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PHYSICAL GEOGRAPHY.

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JOHN YOUNG, M.D., L.R.C.S. EDIN., F.G.S., F.R.S.E.,

REGIUS PROFESSOR OF NATURAL HISTORY IN THE UNIVERSITY OF GLASGOW,
FORMERLY OF THE GEOLOGICAL SURVEY OF GREAT BRITAIN.

NEW YORK:
G. P. PUTNAM'S SONS,
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Willst du dich am Ganzen erquicken?
So musst du das Ganze im Kleinsten erblicken.
GOETHE'S *Sprüche.*

THE teacher need make no apology for adding another to the list of text-books, if he supplies what he believes, rightly or wrongly, to be a want, if he does his work conscientiously, and if he is content to abide by the verdict which natural selection will make abundantly clear to himself and his publisher.

I have endeavoured to give greater continuity to the Geological argument than is usual in books on Physical Geography, and in doing so it has been necessary to introduce topics which are still under discussion. Had space permitted I should have done so to a larger extent, knowing by experience that students learn more from careful analyses of current controversies than from the safer but less interesting lectures which are confined to the recapitulation of "generally accepted conclusions."

Every teacher can devise questions on each chapter for himself, but the private student will derive much assistance from the "Two Thousand Questions on Physical Geography," by Professor Ansted. By their aid he will be able, not merely to test his own progress, but to acquire the art of answering questions, which, apart from its special value in this age of examinations, is an admirable training in the art of studying.

I am greatly indebted to Mr. James Macaulay, of St. Stephen's School, Glasgow, for important assistance and valuable advice in the preparation of this book. To him I am indebted for the comparative Table of Centigrade and Fahrenheit Degrees.

My former colleagues on the Geological Survey, especially Professor Geikie, Mr. James Geikie, and Mr. Whitaker, will find that I have borrowed largely from their conversations, and from their published papers. I trust they will forgive me for thus laying them under contribution, if I have succeeded in fairly representing their views.

To Professor A. C. Ramsay, Director General of the Geological Survey, I am under obligations which the frequent references to him do not exhaust, and I should have asked permission to dedicate this volume to him but that the association of his name might have been misconstrued into an unauthorised guarantee for a mere text-book. He has, by his writings and his personal influence, done more than any living Geologist to establish the connection, rather the identity of Geology and Physical Geography, which I have tried to make clear. In his and Professor Huxley's contributions to the Proceedings of the Geological Society, the future historian of Geology will recognise the convergence of the geological and zoological lines of investigation. The reconciliation of the physical investigations which Hutton initiated, with the zoological enquiries to which Cuvier's name gave for many years undue weight, is not yet complete; but Professor Ramsay has pointed out the way from the geological side. I shall have earned my reward if this volume is found to be entitled to a share in the work which he has done so much to advance.

JOHN YOUNG.

UNIVERSITY OF GLASGOW,
November 1873.

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PHYSICAL GEOGRAPHY.

INTRODUCTION.

PHYSICAL GEOGRAPHY is the history of the Earth, its past and present, interpreted by the light of Astronomy, Geology, and Biology. It is not a mere description of the features of sea and land, for these, as we now see them, are only one phase in a series of events of which we do not know the beginning, nor can we foretell the end. The enumeration, however accurate and exhaustive, of the movements of Ocean and Atmosphere is comparatively useless, unless we can arrive at some general principle to which these are subordinated. Nor is it enough to know the plants and animals which occupy the various regions of land and water: we must seek for the explanation of their diversity, and ascertain if the distribution of organised beings in the past throws any light on their relations in the present.

Physical Geography is, to adopt the elegant figure of M. Guyot, the anatomy and physiology of the earth. Geology deals with the anatomical problem, what are the materials of which the earth's crust is composed, and appeals to chemistry and physics for aid in elucidating the details of the processes by which these materials come to exhibit their present arrangement; it illustrates, by phenomena going on around us, the agencies by which the surface configuration has been modified from time to time; but with this purely anatomical investigation its labours end. It is a part of the duty of the zoologist and botanist to determine, by reference to their comparative structure, the animals or plants which now and in the past have lived on the earth, and to group them so as

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her inhabitants, even the nature of her political institutions have been to a large extent dependent on events long anterior to the advent of man. Similar illustrations might be drawn from the history of other countries, but few furnish a similarly connected and simple narrative.

It is impossible within the compass of a volume such as this to do more than touch incidentally on the leading generalizations which are now regarded as sufficiently established to be safely put before the student. It is necessary to give a brief summary of the principal astronomical facts which must be borne in mind in the investigation of currents, climates, and seasons, and to state as concisely as possible those geological processes, the operation and results of which will be considered in the immediately succeeding chapters. Geology and Physical Geography are so intimately associated that it seems unfortunate that both terms should be retained. The dismemberment of one science was useful in those earlier days when, there being no recognised past in the material world with which at least man had any concern, the history of the earth was summed up in mineralogy and preconceptions, but the dismemberment is now arbitrary and misleading.

CHAPTER I.

SECTION I.

The Earth: its Dimensions—Equatorial Protuberance—Axis of Rotation: Limits of its Oscillation—Ecliptic: Influence of its Obliquity on the Distribution of Light and Heat—Mass and Density of the Earth—Opinions as to Internal Fluidity; Underground Temperature; Secular Cooling—Eccentricity of the Earth's Orbit; Limit of Variation—Precession of the Equinoxes—Disturbing Influence of Planets—The Moon: its Distance; its Mass..

THE Earth is one of the planetary bodies which, revolving round the Sun as a centre, make up the Solar system. The size of these bodies is unequal, and some of them are only secondarily related to the Sun as a centre, since they revolve as satellites around other bodies.

1. Dimensions of the Earth.—The mean diameter of the earth is 7912 miles, the equatorial or larger diameter being 7925·6 miles, and the polar 7899·1. The difference between these dimensions, 26·5 miles, represents the amount of polar compression which gives to the globe the figure of an oblate spheroid. Nor is this the only inequality, since it is asserted that the equatorial diameters do not all agree, a difference even to the extent of a mile existing between some of them. We may compare the equatorial protuberance to a layer laid on a sphere, so that we have around that region of the earth a mountain mass, so to speak, with slowly sloping sides. On the assumption of the former plasticity of the earth's mass, the oblate spheroidal form is that which a sphere, revolving on its own axis, would naturally assume. It has been suggested that the tapering of continents southward was connected with the rotation form of the earth's mass; but, in the first place, there is no reason to believe that the earth now alters its form otherwise than by the modification of the surface effected by denudation and local subterranean movements; in the second place, the attenuation commences to the north of the equator, and some of the pyramids, in place of tending away from, tend towards the equator; and thirdly, marine sedimentary deposits prove that at one period more or less of the region of most rapid rotation was itself the seat of an ocean. The stability of the axis of the earth is a necessary consequence of the equatorial protuberance, since any disturbing force which would be sufficient to shift the axis of rotation, must be very powerful to overcome the obstacle provided by this great mass. Hence, any departure from the normal position of the polar axis is within very narrow limits; and, in point of fact, there is a constant oscillation in the endeavour to restore equilibrium. The inclination of the polar axis to the plane of the earth's orbit, that is, to the ecliptic, is 23½°, but it is known that this is diminishing at the rate of 48″ in the century; and, after attaining its maximum, will move in the opposite direction, the range of variation being 1° 21′.

2. **Distribution of Light and Heat.**—As a consequence of this obliquity the earth in its movements round the sun receives heat alternately to the north and to the south of the equator; so that, in place of an equatorial band of warmth and two polar zones of constant and extreme cold, we have alternations of temperature and more equal distribution of light; for, if the sun were always vertical to the equatorial area, a considerable tract of the arctic and antarctic circles would be in deep twilight, and the duration of day and night would be equal all over the rest of the globe. This distribution of light and heat equally over the north and south hemispheres promotes equilibrium in all other respects. As we shall afterwards find, the movements of the atmosphere and of the ocean are, doubtless, powerfully affected by the rotation of the earth, but are chiefly determined by the physical features of the land.

3. **Mass and Density of the Earth.**—The mass of the earth is about 259,801 millions of cubic miles, and the *specific gravity* has been determined by experiments to be

from 5 to 5·67, the extreme amount having been observed by Airy who, from experiments at the mouth and bottom of a coal pit, estimated it at 6·56. Intimately associated with the estimate of the density of the mass is the question of its internal condition.

4. Internal Fluidity.—Different views are entertained at the present time as to the existence or not of a central fluid mass, and the observations upon which is based the inference that there must exist such a fluid core are, that at 2151 feet the temperature is 75°F. (24°C.), that of a stratum at 17 feet being constantly 51°F. (10·5°C.). In Cornwall 32·5°C. have been recorded at a depth of 1200 feet, and the borings at Creuzot show that there is an increase of temperature by 1°F. for every 55 feet of descent, but after 1800 feet have been reached the increase is 1° in 44 feet. The existence of hot springs, issuing from vaults which extend to very considerable depths, likewise point to the conclusion that a very high temperature exists some distance beneath the surface; and the outpouring of lava from so many orifices has hitherto always been looked upon as only explicable on the assumption that a great reservoir of molten matter uniformly underlay the crust. If the increase of temperature goes on increasing with depth according to the calculations at Creuzot, then we should expect to find that, at 50 miles beneath the surface, the heat would be 4600°F., that is considerably greater than is required to fuse platinum. It has been calculated that the sedimentary strata represent a thickness of 20 miles, and, on the assumption of a uniform increase of temperature, we should find that the sedimentary strata were at their deepest part subjected to a temperature capable of melting brass, and probably not far short of that at which gold is melted; so that a very short distance comparatively beneath the crust would bring us to a region in which every known substance would be in the fluid condition. But it is unknown how far increase of pressure has to do with the keeping matter in a solid condition even at very great temperatures, and, at the same time, when it is remembered that the specific gravity of the earth is estimated at 5 or 6, while none of the constituents *of the earth's crust* have a higher specific gravity than 3, it is obvious that pressure and heat have opposite tendencies, and that the influence of pressure is greater than that of heat; for, while the compressed rocks would give a specific gravity very much higher than that of the earth's mass, the expansion consequent upon the existence of heat in their substance keeps it down to the more moderate limit. Sir William Thomson has investigated the question of the cooling of the earth, and looks upon the increase of temperature from the surface downwards as proof of the constant loss of heat from the globe, the heat radiating into space without sensibly elevating the temperature of the upper crust through which it passes. The continuance of such a loss of heat involves belief in the occurrence of a period at which the earth was a fluid mass, and Sir William Thomson has fixed that period at not less than 200 millions, nor more than 400 millions, of years ago; the probability being that 100 millions of years is the limit of geological history, and that, prior to that time the earth's surface was unfit for the maintenance of animal or vegetable life. But he does not consider it probable that the crust was formed, as is commonly assumed, by the consolidation of an outer layer: he believes that this outer layer did not acquire its firmness till the globe had become very nearly solid; and that, as the consolidation commenced from the centre and went towards the circumference, the last portion to be formed would be the external crust. He agrees with Mr. Hopkins in believing that within the crust, cavities or chambers exist in which molten matters are found, and that it is this cavernous layer, separating the external crust from the solid core, which is the source of volcanoes and their attendant phenomena, whose development is excited either by the breaking in of the roofs, or by the introduction of matter, chiefly water, from the exterior, or by the subsidence of the crust compressing the fluid matters contained in the spaces. While it is certain that the earth has consolidated from the fluid state, the vagueness of the limit above assigned has been made ground of objection, and it has been pointed out that there is no means of determining the rate at which radiation has taken place in the past, since at present the atmosphere checks radiation in proportion to the quantity of aqueous vapour it contains. These and other considerations have been advanced, not in disproof of the statements as to the fact that there is a loss of temperature, but as suggesting that our knowledge is not yet sufficient to fix the rate of loss, still less the period when the globe became habitable, and when it shall cease to be so. The organic world does not furnish any guide to the solution of the problem, and this speculative question must, therefore, be left in the meantime.

5. Eccentricity of the Earth's Orbit.—The path described by the earth round the sun is an ellipse, of which the sun occupies one focus. The amount of eccentricity varies, so that, as calculated by Mr. Carrick Moore, the difference between the earth's greatest and least distance from the sun was as given in the following table :—

250,000	years before 1800, A.D.,	4⅓	millions of miles.
210,000	,,	10½	,,
200,000	,,	10¼	,,
150,000	,,	6	,,
100,000	,,	8⅓	,,
50,000	,,	2¼	,,
0	,,	3	,,

The orbit, therefore, made its nearest approach to a circular form 50,000 years ago, and is now tending again towards greater eccentricity.

6. Precession of the Equinoxes.—The rotation of the earth on its axis gives the alternations of day and night; but its revolution round the sun gives with the obliquity of the axis the seasonal differences, as well as the alternation of these seasons in the northern and southern hemispheres. Twice every year in the course of its revolution the earth arrives at a point where the ecliptic cuts the equator, and the day and night are then equal all over the earth; twice every year the earth arrives at a point where the sun illuminates the northern hemisphere and the southern hemisphere respectively, and when the sun has attained its greatest northern limit, the summer solstice of the northern hemisphere takes place, the sun thereafter declining to the south, till, passing the equator, the summer solstice of the southern hemisphere is reached in its turn. If the revolutions of the earth round the sun were performed in equal times, the solstice would always occur at the same point in the orbit. But retardation makes the earth arrive at the same point successively a little later at each revolution, and thus the solstice of the northern hemisphere, occurring at one period when the earth is nearest the sun, or in perihelion, gradually comes round later and later till it coincides with the earth's greatest distance from the sun, or aphelion. But another influence also comes into play, namely, the revolution of the apsides, the long axis of the earth's elliptic orbit slowly changing its direction under the same disturbing influences. By the joint influence of precession and the revolution of the apsides, the period in which the earth completes this cycle is 21,000 years: within that time the north pole will have passed through every intermediate position between that when its winter was in aphelion back again to the same point.

7. Amount of Heat received by the Earth.—The total amount of heat received by the earth is in the inverse proportion to the minor axis of its orbit; a larger amount, therefore, is received during extreme eccentricity of the orbit than when it is more nearly circular. The obliquity of the ecliptic, or the inclination of the earth's axis to the plane of its orbit, varies as has been said: at its maximum the polar regions would receive $\frac{1}{18}$ more of heat than they do at present, and at its minimum the amount of heat would be correspondingly diminished. It is unnecessary to speak of the theoretical consequences of these various astronomical conditions, since, in discussing changes of climate the actual results, controlled by the physical conditions of the earth's surface, will be summed up.

8. Disturbing Influences of Planets.—The disturbing influences alluded to above are due to the attraction of the planets Jupiter, Saturn, and Mars, superior planets, as they are called, whose orbits, that is to say, are external to that of the earth, and by Venus among the inferior planets, or those whose orbits are internal to that of the earth.

9. The Moon.—The moon describes an elliptic orbit, having the earth in one of its foci. Its mean distance from the earth is 226,000 miles, and its orbit is inclined to the ecliplic at an angle of 5° 8′ 48″, so that its altitude is greater and less than that of the sun at its summer and winter solstices. Its mass has been determined as $\frac{1}{81\cdot4}$ of the earth; its bulk to be $\frac{1}{49}$ of the earth, and its density ·6. Its rotation is performed in the same time as its revolution round the earth, the lunar month or period of these movements being 29d. 12h. 44m. 2·87sec. The attraction excited by this satellite on the earth, and especially its influence on the tidal phenomena, will be discussed in a future chapter.

The relations of the other planetary bodies to the earth belong to the domain of astronomy, from which we borrow the fact that their attraction on the earth's mass varies with their proximity to or distance from it, according as their elliptic orbits bring them nearer or carry them farther away.

SECTION II.

Composition of Earth's Crust—Table of Formations—Interpretation of such Tables—Comparative Sections in Britain—Unconformity—Sedimentary Formations not all Marine.

10. Composition of Earth's Crust.—Whatever may be the composition of the interior of the earth, it is certain that its surface consists of various materials, arranged either in regular masses or irregularly comingled. The chemical substances entering into the composition of the earth's crust are, of course, all those which are known to the chemist, but the proportions in which they exist are exceedingly various; thus calcium carbonate is almost universally found, whereas phosphorus is comparatively rare. The quantity of each of the elements which enter into the composition of the stratified deposits, and their relative importance, are fairly represented by the following analysis given by Roscoe from the examination of palæozoic rocks. In 100 parts, by weight, there are of

Oxygen,	44 to 48·7.	Calcium,	6·6 to 0·9.
Silicon,	22·8 to 36·2.	Magnesium,	2·7 to 0·1.
Aluminium,	9·9 to 6·1.	Sodium,	2·4 to 2·5.
Iron,	9·9 to 2·4.	Potassium,	1·7 to 3·1.

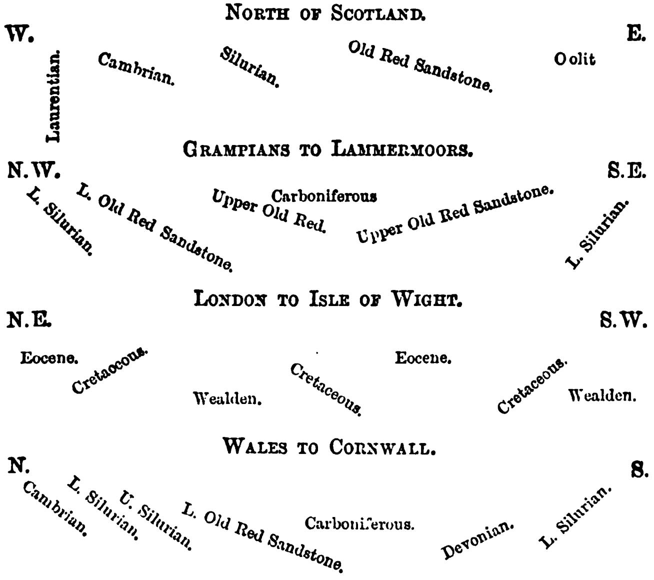
The composition and mode of combination of the different elements is likewise very various. The discussion of these differences belongs to the province of chemical geology, but it will be necessary to point out in a general way, the manner in which the different ingredients are presented to the field observer.

11. Formation of the Earth's Crust.—Commencing at the surface of the earth in temperate regions, we find a variable amount of soil overlying gravel, sand, and clay, all more or less incoherent. Beneath these we come to harder material, disposed in layers, the inclinations of which to the horizon are widely different, ranging from horizontal to perpendicular. As every one of these layers owes its existence to the disintegration of a previously consolidated mass, it is obvious that there must be a point beyond which it is impossible for us to trace the stratified rocks, a point at which the earliest formed strata have disappeared, and that point is reached in the Laurentian series; for though these have obviously been deposited as sedimentary strata, yet the sources of these sediments are nowhere to be recognised now. Laurentian rocks are therefore not the oldest, but the oldest known components of the earth's crust; all the succeeding formations, tabulated as follows,—

Tertiary or Neozoic or Cainozoic.	Recent.	*Secondary or Mesozoic.*	Cretaceous.	*Primary or Palæozoic.*	Permian.
	Pleistocene.		Wealden.		Carboniferous.
	Pliocene.		Oolitic.		Old Red.
	Miocene.		Triassic.		Silurian.
	Eocene.				Cambrian.
					Laurentian.

are derived each from that which had gone before. Calculations have been made as to the thickness of the earth's crust, the greatest thickness of each of these formations, or their mean thickness, according to the views of the calculator, being taken and added together; the result is very serious misapprehension of the relations of the strata to each other. For although a table, such as that above, represents every formation as if it lay in contact with one above and one below, and though it thus suggests the presence of all these layers as the normal condition of the earth's crust, it must be borne in mind that it is impossible for all of these strata to exist at every point of the earth's surface, without our imagining that the seas and lands of the past had alternated, and had, each of them in turn, covered the surface of the globe, a supposition which is contrary to analogy and to experience. A geological section or table is true only for the locality at which it is taken. Movements of elevation and subsidence are constantly going on at various points, and the positions of sea and land are constantly shifting; it will be apparent that every change in the position of land and water means addition to, or diminution of, the amount of sedimentary layers, or even the entire arrest of their deposition. The persistence of continental conditions for a long period necessarily prevents the formation of sedimentary accumulations over that area, and thus we have in the British Islands a remarkable difference in the succession of the rocks at different parts, the following being very good examples of what it is desired to explain:—

COMPARATIVE SECTIONS IN UNITED KINGDOM.


NORTH OF SCOTLAND.

GRAMPIANS TO LAMMERMOORS.

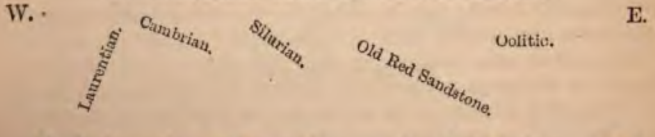
LONDON TO ISLE OF WIGHT.

WALES TO CORNWALL.

12. Unconformity of Formations.—The thickness of the stratified portion of crust may or may not be twenty miles, but the calculations upon which it is based are futile, and apt to convey an erroneous notion of physical geography. If our opportunities of observation were complete, we should be able to form a picture at every epoch of the changes of land or water; we should be able, from a comparison of sedimentary deposits and the areas they occupy, to fix the position of every change. But, in the first place, the geological record is not complete, denudation having removed a great many of the strata; and, in the second place, we have no guide to the absolute time which may have elapsed between any two events. Thus we find in Scotland that the old red sandstone is covered by the oolites, whereas in England the carboniferous epoch, the permian, and the triassic intervened between these two sets of beds; but we cannot tell whether the interval represented by the absence of deposit is greater, equal to, or less than the interval represented in England by all these formations, though the probability is that it was about the same.

If every one of the formations mentioned in the table represents the sea bottom, and if we find that any one ot these formations is in contact with, not one, but several of those which were formed before it, it is obvious that the sea bottom upon which it is laid down was not uniform, and was not made up of the same parts. This relation, which is known as unconformity, may be represented by the subjoined diagram, in which the planes of the strata are indicated by the slope of the printed names.

TRANSVERSE SECTION OF SCOTLAND.



13. Sedimentary Formations not all Marine.—This section shows a number of unconformities, each one of which repeats exactly the same steps. We have, first of all, the deposit of the strata from water, then elevation until they have lost their approximate horizontality; we have them brought within the denuding action of the waves of the sea, or they may be elevated still more so as to be acted on by the atmosphere; and, again submerged after their upturned edges had thus undergone considerable reduction, they become the seat of fresh accumulations. The time occupied in these processes is unknown; it may be long or it may be short, for we cannot tell how many times these processes may have been repeated, we cannot tell how many accumulations have been laid down thus unconformably, have been swept away, and upon the fresh worn surface of the subjacent rocks another pile deposited. We see in fact only the last step in the process; we cannot tell how many similar steps had occurred before. But from the statement that all these formations represent sedimentary deposits, and by that is usually meant marine accumulations, some deduction must be made. Professor Ramsay has given good reason to believe that the cambrian, the old red sandstone, the permian, the triassic, and part of the carboniferous formations, represent the remains of continental areas, of land surfaces, or of land locked basins in which a meagre fauna lived, and in which the deposits were largely chemical. This is among the first attempts that have been made to connect the continents of the present with those of the extreme past; and it seems as if we were very nearly able to say that the land surfaces of the triassic times are continued by the present continents, and that, extensive as may have been the upward and downward movements and other changes of their surface, these have not been simultaneous at all points, and thus the direct, uninterrupted transmission of plant and animal life has taken place as unmistakably as it has taken place in the ocean.

In a subsequent section, an attempt will be made to show how a continent may gradually become developed or evolved by the addition of layer to layer, by the gradual elevation of each layer, as it has been formed, to become the shore of the land.

SECTION III.

Most Common Minerals—Table of Rocks—Difficulty of Classification: Transition Groups—Mechanically, Chemically, Organically Formed Rocks—Hypogene Rocks.

14. **Minerals.**—The elements which enter most largely into the composition of mineral masses are: hydrogen, chlorine, sodium, potassium, oxygen, sulphur, calcium, magnesium, carbon, silicon, aluminium, iron, fluorine, boron, phosphorus, lithium, barium, zirconium. A mineral is a chemical substance having a definite composition and a definite form; a rock is made up of various minerals in different proportions, and has no definite form. It only concerns the geographer to ascertain the composition and structure of rock masses, or that department which the geologist recognises as petrology.

15. **Rocks.**—Rocks may be grouped as—

A. MECHANICAL.

1. SEDIMENTARY:—
    - *a.* Arenaceous, *e.g.*, Conglomerate. Sandstone.
    - *b.* Argillaceous, *e.g.*, Mud. Clay. Shale.
2. ÆOLIAN:—
    - Blown Sand. Dunes.
3. SUBAERIAL:—
    - Superficial Moraines.
    - Moraine profonde. Boulder Clay.
    - Talus.

B. CHEMICAL.

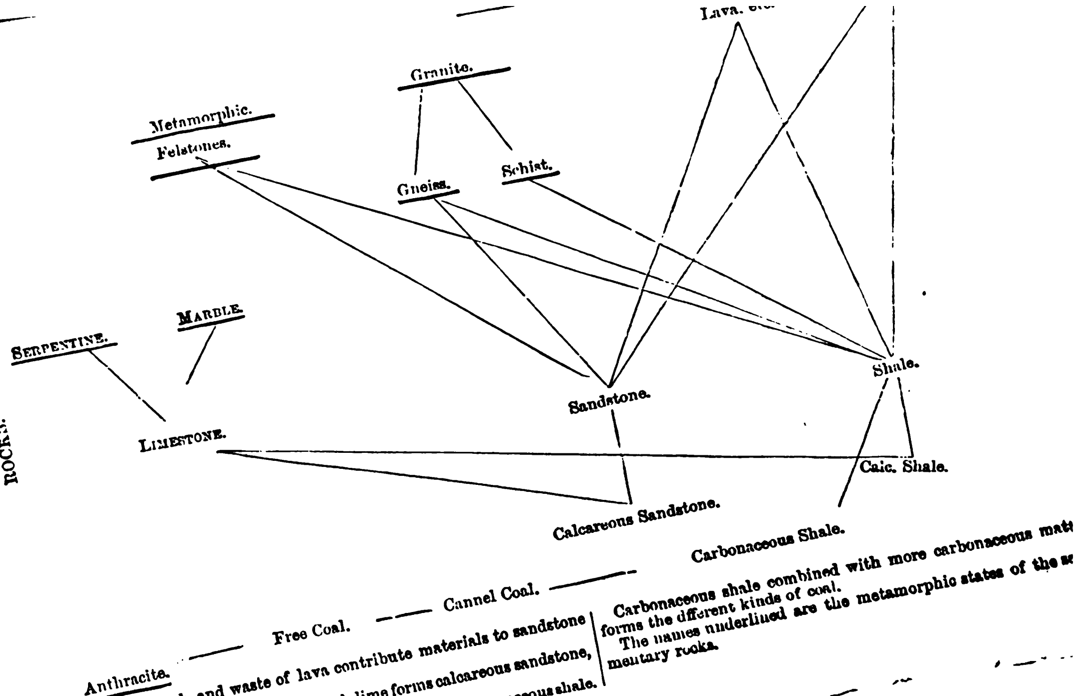
1. Calcareous, *e.g.*, Stalactite. Travertine.
2. Siliceous, *e.g.*, Sinter.
3. Rock Salt.
4. Gypseous.

C. ORGANIC.

1. Calcareous, *e.g.*, Coral Reefs. Ooze.
2. Carbonaceous, *e.g.*, Peat. Lignite. Coal.
3. Ferruginous, *e.g.*, Bog Ore.

D. HYPOGENE.

1. METAMORPHIC:—
    - Quartzite, Hornstone.
    - *Mica Schist, Slate.*
    - *Gneiss, Granite.*
    - Porphyry.
    - Dolomite. Serpentine.
    - Anthracite. Graphite.



Volcanic ash and waste of lava contribute materials to sandstone and shale.

Sandstone or shale combined with lime forms calcareous sandstone, lcareous shale.

[illegible] with carbonaceous matter forms carbonaceous shale.

Carbonaceous shale combined with more carbonaceous matt forms the different kinds of coal.

The names underlined are the metamorphic states of the se mentary rocks.

2. Igneous:—
   - *a.* Volcanic.
     - Felspathic Series, *e.g.*, Trachytes.
     - Augitic Series, *e.g.*, Dolerite, Basalt.
   - *b.* Trappean.
     - Felstones.
     - Melaphyre.

Ashes.
Breccias.
Agglomerates.

16. Classification.—These groups cannot be regarded as sharply defined: in each a typical form may be selected, but, except among the lavas and perhaps a few granites, we do not find perfectly simple representatives of the family characters. The difficulty of classification will appear in the sequel; but the accompanying diagram gives a general idea of the mutual relations of the groups.

17. A. Mechanically Formed Rocks.—

1. *Sedimentary.*—The rocks formed by deposit from water constitute the great bulk of the stratified formations, and the two ingredients, silica and alumina, which form their greatest mass, characterise, according to their predominance, the sandy and the clay series, arenaceous and argillaceous, but they are seldom found pure.

The finest arenaceous rocks, the purest sands, or the finest grained sandstones, present quartz masses comminuted to the smallest possible size. The series commences with breccia, or angular fragments which have been disengaged from rock faces, but have not undergone any action by which their angular asperities might be removed. Water-rolling is the most powerful agent in smoothing and polishing in all directions, a pebble being, in popular language, a rounded piece of quartz equally smooth at all points; but it is convenient to use the word for any uniformly rounded fragment. The longer the friction is continued the smaller does the fragment become, so that the coarse shingle of the sea-shore, which, when consolidated, yields a conglomerate, passes into gradually finer gravels—fine sand being the last term in the series. The consolidation is effected in the case of sand by compression, by infiltration of iron and lime from the strata above, or by the solution of calcareous fragments, as of shells, which may have been enclosed in it. Breccias and conglomerates *become coherent* rocks by intermixture with sand, and the pressure which effects consolidation may be guessed from the fact that the pebbles are sometimes indented at their points of mutual contact. Sandstones contain varying quantities—sometimes minute, at other times considerable—of clay, iron, calcareous, felspathic, and organic matters; and thus we have transitions to shales, ironstones, hypogene rocks, limestones, and coals. The debris brought into the sea by streams, or derived from the waste of shores, is sifted in the sea, and deposited according to its relative weight; gravel, sand, and mud form, generally speaking, successive zones of deposit parallel to the coast. Sandstones occur massive, without stratification planes, forming the liver rock of quarrymen, or divided into seams of various thickness separated from each other by layers of other materials. The value of sandstone as a building material, is in proportion to the closeness of its grain, the presence of stratification planes destroying the free working in all directions.

Clay is the characteristic material of argillaceous rocks. The silt of a river is a heterogeneous substance, consisting of fine mud, sand, organic and chemical matters, which are gradually separated. The aluminous matter is always fine grained, and the glacier detritus can only be said to present a greater tenuity of its materials, because the sand which it contains has been ground into an unusually fine powder. The only pure clays are those derived from the decay of felspathic rocks, the result—kaolin, porcelain clay, or meerschaum—consisting of hydrated silicate of alumina, from which other ingredients have been washed out; and those clays on which a similar depuratory action has been exercised by vegetation. The fire-clay found along with coal seams is the representative of the white clay on which peat rests, and the principal impurity of both is a small quantity of carbonaceous matter. Clay as a stratified deposit forms shale, which is usually extremely fissile; but this fine lamination must not be confounded with the division planes of slate, which form a structure superinduced upon and not necessarily coinciding with the planes of original stratification. As an increasing quantity of sand would lead into sandstone, so an increase in the carbonaceous or calcareous admixture would give the transition from clay to coal or limestone. A small quantity of lime gives the fertile marls, and of sand gives to loam its pervious character. The consolidation of this last variety yields the mudstones of the older formations, which are less fissile and tougher than the purer shales. Lastly, the addition of volcanic ashes to shales in course of formation gives a nearer or more distant approach to volcanic rock in proportion to the quantity introduced.

2. *Æolian rocks* are the blown sands of the desert and the sea shore. They are sometimes, especially the latter, regularly stratified, and shells, blown up from the beach, are often found in the laminæ. This kind of formation is only recognisable in the present, its incoherence and the circumstances of its accumulation preventing its preservation in the form in which it was first laid down.

3. The term *Subaërial* is intended to apply to those materials which are derived from atmospheric waste, but have not been reassorted in water. The talus found at the foot of every cliff, consists of debris which may be washed down in part by rain, but the quantity of water is not sufficient to give it a stratified character. The coarser materials are found at the bottom of the slope, which has the fan-shape characteristic of all sediment allowed to spread without restraint from a single point. The glacier debris will be referred to in a subsequent chapter. Meanwhile, it may be mentioned, that though the Moraine profonde may have more or less of an alluvial aspect, an imperfect stratification being discernible in it, the rearrangement of its materials has not the regularity even of river deposits, and in the case of the boulder clay or till, the distinction is well known between the pell-mell aspect of the great mass, and the regular stratification of those parts which have been laid down in the sea, or upon which the sea has come to act.

18. B. Chemically Formed Rocks.—The limits of this group are very indefinite, but well marked types of rock may be found which, though deposited in water or by water, have their final form very unlike that of true sedimentary rocks.

1. *Calcareous* deposits take place in caves, and, on a small scale, in cellars and under bridges, where water drops down carrying an excess of carbonate of lime. The water which falls on the ground evaporates or runs off, leaving a calcareous

deposit which may come to form very thick layers of stalagmite. The falling drop also parts with its lime, which gradually forms a dependent rod like an icicle; and the stalactite and stalagmite may meet, finally filling up the cavern with a spongy mass of variously coloured carbonate of lime, in which crystallization may afterwards take place without destroying the lamination. Travertine is a porous limestone deposited by precipitation from the waters of calcareous springs and streams. It forms masses which, as at San Filippo, may be 250 feet thick; and a thickness of one foot has been laid down in about four months. If fragments of foreign matter are enclosed in it, the lime may arrange itself round these in concentric masses giving a spheroidal texture.

2. The *Siliceous sinters* found around thermal springs, are precisely similar to the calcareous travertines. The silex is deposited on the cooling of the warm water charged with soda, which kept it in solution at a high temperature.

3 and 4. *Rock salt* is found in lenticular masses, 60 or even 90 feet thick in England. In France the layers are each of them thinner, but at Vic 180 feet of salt are found in 650 feet of strata. Rock salt (sodium chloride) and gypsum (anhydrite, and hydrated calcium sulphate) are usually found in association; they occur in various formations, but their remarkable development in the triassic strata, and others whose tints are red, yellow, or green, according to the iron salt they contain, furnishes an important evidence in favour of Professor Ramsay's theory, that these formations were deposited in inland seas. Rock salt is also found in considerable quantity saturating the soil of inland plains, or deposited round the shores of land-locked basins.

19. C. Rocks of Organic Origin.—The segregation of various substances by plants and animals is doubtless a chemical process; but being determined by the living tissues of organised bodies, and yielding rock masses of very different forms and relations from those of the last group, it is at least convenient to keep them apart.

1. *Calcareous.*—The coral reefs of tropical and sub-tropical seas, and the isolated corals of other oceans, offer the largest ratio of chemical substances to living tissues that we know

of in nature. The enormous thickness of some reefs makes them very important members of the stratified series, while their disintegration forms sedimentary deposits whose ultimate organic origin is obscured. Their interest is increased by the fact that they contain carbonate of magnesia along with carbonate of lime, and thus these two minerals are found in conjunction, which, as in the permian strata, are believed to represent metamorphism. The oaze which covers the floor of the Atlantic and other oceans, consists of about 85 per cent. of calcareous matter, derived from the tests of Globigerinæ (Huxley); 10 per cent. of silicious matter of inorganic origin, or obtained from diatoms and other lowly organisms, with silicious coverings; while the remainder consists of the debris of molluscs, crustacea, and other marine animals which are enclosed in calcareous shells. This fine soft sediment hardens on exposure, and both in composition and structure is well nigh identical with the earthy limestone forming the white chalk. Mr. D. Forbes finds that white chalk contains 94 to 98 per cent. of carbonate of lime, oaze not more than 60 per cent. He thence concludes that oaze would yield a calcareous shale. The proportion of lime probably depends on depth; the generalisation may therefore in the meantime be accepted as in the main correct. Lacustrine limestones or marls are formed in many small basins, and are found on a large scale in Lake Superior. The varieties of limestone are considerable. The white chalk has already been mentioned; it is earthy in England, more compact in France. The limestones of the carboniferous period are seldom quite pure, giving transitions into sandstone and shale. Rich as they are in fossils, the quantity of lime is greater than the fossils preserved will explain; and it is probable that the great mass consists of debris of organisms similar to those which have come down, while it is not unlikely that the deep seas of ancient periods contained oaze similar to that of more recent times. Bituminous and fetid limestones owe their characters to the presence of organic matter. Limestones may be earthy, compact, or crystalline, according to their purity and the conditions to which they have been subjected since their formation. The oolitic and pisolitic structures are, like the spheroidal condition of travertine, due to the presence of small foreign bodies; but the isolation of the spherules has been effected by the rolling of the first concretions to and fro, so that they come to consist of concentric layers. Siliceous infiltrations may give great hardness, while decomposition yields rottenstone. Conglomeratic or brecciated limestones are found under circumstances suggestive of the waste of islands in their vicinity during deposition. The Broken beds of Portland have been accounted for by supposing the deposit of lime on a mass of vegetation, whose decay and collapse fractured the layer, while continued deposit of lime recemented the whole.

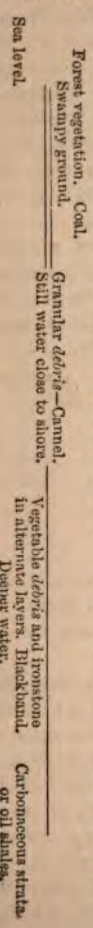
2. The *carbonaceous* group is the most important economically. The following table, given by Dr. Percy, illustrates the composition of various members of the coal group, the carbon being taken as 100. The last column shows the excess of hydrogen above that required to make water:—

	Carbon.	Oxygen.	Hydrogen.	Excess of Hydrogen
Wood,	100	83·07	12·18	1·80
Peat,	,,	55·67	9·85	2·39
Lignite,	,,	42·42	8·37	3·07
10 Yard coal, Stafford,	,,	21·23	6·12	3·47
Steam coal, Tyne,	,,	18·32	5·91	3·62
Pentrefelin coal, S. Wales,	,,	5·28	4·75	4·09
Anthracite, Pennsylvania,	,,	1·74	2·84	2·63

This table shows the decrease of the other ingredients in proportion to carbon, anthracite being the extreme form of the metamorphism of coal, in which the volatile matters have been largely expelled.

In the conversion of wood into coal, part of the hydrogen is eliminated with carbon, as marsh gas (CH_4), a part unites with oxygen to form water, and part of the remaining oxygen unites with the carbon to form carbonic acid (C_2O_4).

Coal is formed from the decay of vegetable matter, and the process may go on where the vegetation grew, or the finer debris may be washed down into pools, settling down there to form the fine grained compact cannel or gas coal. The ordinary bituminous coals, as they are called (though they contain no bitumen, no substance, that is to say, which is soluble in ether or benzole), have, for the most part, an imperfect cuboidal structure, the planes by which the mass is divided being vertical to those of stratification. These joints result from the pressure to which the once soft mass has been subjected, the bulk of the original vegetable matter having been, it is calculated, eight or twelve times that of the coal. The seams usually rest on fire-clay, the soil on which the vegetation flourished, while upwards they may pass into carbonaceous shales. But the coal itself is remarkable for its freedom from sedimentary materials, a condition only compatible with its formation beyond the reach of sea or rivers. The occasional intersection of coal fields by bands of gravel, the ordinary debris of a river channel, confirms the view that the coal swamps were analogous to those of a delta like that of the Mississippi, the plants decaying on the islands between the streams, being protected from incursions of alluvium by the thick undergrowth all round. The subaqueous deposit of cannel coal is rendered more probable by the horizontal passage of cannel into blackband ironstone, with which are associated the remains of amphibians, so that the series probably was as in the adjoining table.


Forest vegetation. Coal.
Swampy ground.
Granular *debris*—Cannel.
Still water close to shore.
Vegetable *debris* and ironstone in alternate layers. Blackband.
Deeper water.
Carbonaceous strata or oil shales.
Sea level.

The oil shales mentioned in the last line of this diagram, are now an important article in Scottish manufactures. They are ordinary shales, saturated with animal matter derived from the decay of minute entomostracan crustaceans and of vegetable matter, the former being the characteristic inhabitants of brackish and stagnant fresh waters.

3. Ferruginous deposits, whose position is determined by organic bodies, are illustrated by the bog iron ore, which forms deposits sometimes of tolerable size in peat swamps, concentrated on particular spots by the partially decaying plants. The segregation of the iron in carboniferous times was determined likewise by the vegetation.

The substances above mentioned form rock masses, whose primitive condition is for the most part recognisable. But except those which are now forming at the surface, none are absolutely in their primitive state. Consolidation by the pressure of a superjacent stratum, has effected a certain change, and as pressure increases, layer being added to layer, infiltrations of fluid also take place, carrying downwards, in solution, substances contained in higher strata. Thus both chemical and textural changes occur in proportion to the age of the deposit, without, however, the characters of the rock being obscured. But other changes take place beneath the surface, metamorphism altering both the chemical and physical composition of the masses, without, at least. in general, destroying their relations, while igneous fusion reduces the whole to a uniform condition both of texture and composition. These changes go on at different depths beneath the surface. Hypogene or subterranean is therefore the most convenient common designation for both kinds.

20. D. Hypogene:—

1. *Metamorphic.*—The consolidation of an ordinary sandstone still leaves the rounded form of its ultimate grains recognisable; but in quartzite, or sandstone which approaches more or less towards the condition of homogeneous quartz, the granules become adherent or confluent, their partial solution having been effected by warm alkaline waters. Hornstone and lydianstone are extreme cases of this change in siliceous strata containing a considerable quantity of clay.

Mica schist, chlorite schist, and the like, are sedimentary rocks, some of whose ingredients have been separated out and arranged in planes parallel to those of original stratification. This rearrangement is known as foliation, and it reaches its highest development in gneiss in which quartz, felspar, and mica are disposed in alternate layers. But these are not extensive, the short fusiform masses showing general parallelism only when looked at from a little distance. The same ingredients are united in granite without the slightest approach to order. Though some granites may be of igneous origin, just as some rocks lithologically identical with trap are of metamorphic origin, the greater part of the granites are the representatives of sedimentary strata altered in place. The granitic axis often spoken of in the case of mountains is the central, perhaps the deepest part of the mass, but its presence is no proof of its antiquity, since granite may be of any age, from the Laurentian down to the tertiary granite of the Alps. In syenite, hornblende is associated with the ingredients; hypersthene and diallage, members of the group of augitic minerals, may be present in such quantity as to confer their names on the rock in which they are found.

In the foregoing rocks the chemical grouping of their ingredients has undergone entire change, the alteration of texture being a necessary consequence. But in the true slates the metamorphism consists in a primary change of structure, the chemical alterations being comparatively slight. Slaty cleavage is due to pressure, and consists in the readjustment of the particles relatively to each other, so that they split in one direction, which may or may not coincide with the stratification planes. The cleavage planes are straight, parallel to each other, and traverse the strata irrespective of their curves.

The trap rocks of conspicuously igneous origin are simulated by certain masses of eminently felspathic character, which, however, represent fine grained as well as conglomeratic sedimentary rocks, whose place they occupy, sometimes alternating with the unaltered strata. These rocks in South Ayrshire are described by Mr. James Geikie, *Quart. Jour. Geol. Soc.*, xxii.

The calcareous rocks are represented by crystalline limestone, such as may be produced artificially by heating chalk under great pressure, the carbonic acid being prevented from escaping; by dolomite, in which carbonate of magnesia has either replaced carbonate of lime by infiltration from without, or the mineral already present in the rock has been gathered along particular lines or at particular points; and by serpentine, which is the extreme modification of a magnesian limestone, the carbonates being replaced by silicates. Serpentine may also result from the metamorphism of some kinds of trap rock.

2. *Igneous Rocks.*—No real difference can be established between the most ancient and modern volcanic rocks, except such as are consequent on the modifying power of external

conditions, or are connected with the absence of any conspicuous orifice of outflow. All the members of this series may be divided, according to their composition, into two groups, in one of which siliceous minerals prevail, in the other the alkaline bases enter more largely. The trachytes contain 66 per cent. of silica, and 17 per cent. of alumina, on an average; the dolerites, or basic rocks, contain 51 per cent. of the former, and 14 per cent. of the latter, with 10 per cent. of lime and 14 per cent. of iron and manganese. The composition of the older rocks, the felstones and melaphyres, which are grouped as traps, is essentially the same, the incoherent materials of the crater of outflow having been removed and having left no trace of its position, but both of the older types have undergone more or less change by pressure and infiltration. The solid rocks have their counterpart in the fragmental series of coarse and fine ashes, which are siliceous or basic according to the character of the lava with which they are associated.

Porphyry is a volcanic rock, in which some of the ingredients have crystallized so as to be prominent in the midst of the matrix. Vesicular structure is due to the presence of enclosed gases in the molten mass, and when these cavities have become filled with solid matters, deposited from infiltrated water, the rock becomes amygdaloidal, the vesicular condition being restored if the contents are removed by subsequent percolation.

Such are the principal kinds of rock which enter into the composition of the earth's crust, so far at least as the geographer requires to consider them.

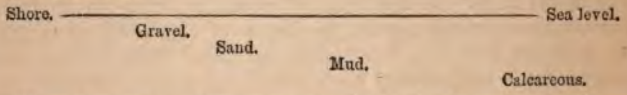
SECTION IV.

Formation of Sedimentary Strata—Disturbances of Sedimentary Strata: Outcrop—Dip—Curves—Faults—Contemporaneous and Intrusive Igneous Rocks—Preservation of Fossils.

21. Formation of Sedimentry Strata.—The sequence of phenomena which terminates in the production of stratified rocks is as follows: Water descending from the atmosphere loosens and removes the particles making up rock masses, and it must be remembered that the term rock is, in geology, used for any accumulation of mineral matter, whatever be its density. The particles thus removed are carried by the stream downwards to their resting place on the floor of the ocean. But they do not travel directly to the sea; they are delayed from time to time by being thrown out of the stream as alluvium, or deposited in lake bottoms; in either case, however, their stay is temporary, since, after a time, they too are disintegrated and carried further down. Every particle in its progress helps the wasting operation, and we have a mechanical abrading power exercised by the river in proportion to the quantity and the bulk of the mineral sediments it carries forward. But the water contains, besides the mechanically suspended matters, chemically dissolved minerals, and thus the solid matter in the stream may greatly exceed the apparent contents. These dissolved substances may either enter into fresh combinations, giving rise to chemical deposits in favourable circumstances, or they may reach the sea, and there assist in the formation of the solid parts of marine plants and animals, and thus, in the end, contribute to the formation of rock. The rain, as it descends through the atmosphere, takes up various gases on its way; chief amongst these is carbonic acid gas, which becomes, when precipitated on the earth, a powerful solvent of calcareous matters. Absolutely pure water can do little in the way of disintegration, if its action is not facilitated by gravitation or by chemical change. The disintegrating influence of the rain is modified by the quality of the surface on which it falls, being slowest upon bare hard rock, into which calcareous matters do not enter; and most rapid upon soft loose soils not protected by vegetation. Two extreme cases, illustrative of this influence, may be referred to: the one is the rainfall on the Khasia Hills, in Bengal, which amounts to 30 inches daily; it washes away the soil from the hill sides, and prevents any vegetation gaining a footing; the other case is that given by Lyell, who relates how deep ravines were excavated in Georgia, U.S., after the cutting down of the forest which had previously protected the soil from the rainfall. As rivers occupy a larger proportional area of the high grounds than do the conjoined streams in the low grounds, where the waters are confined in narrow but deep channels, granular disintegration effected by the atmosphere is greatest in the high grounds. By atmospheric denudation is meant all the waste that is wrought by means of the *moisture* contained in the atmosphere. The form of water varies; the small fine rain does more than the soaking mist in the way of removal; the rapid torrent, hurrying forward numerous pebbles, is efficient both in disintegration and in transport; but in temperate regions the expansive power of frost is one of the most efficient agents in breaking up and removing even the hardest rocks, while, in some tropical and sub-tropical regions, the heat of the sun plays a very important part. The large glacier, formed by compression of the snow into a stream of solid ice, at once disintegrates the surface of its channel, and removes the rubbish; and the features of the country over which ice has travelled, either in the valley streams, known as glaciers, or in the shape of a great sheet of land ice, are characteristic and easily recognised in every region.

The action of the atmosphere, as a denuding agent, is vertical, that is to say, it tends to lower the vertical elevation of the earth by the removal of particles from its surface. The next denuding agent, in point of importance, is the sea, and its action is horizontal, so that, if land were stationary for a sufficiently long period of time, it would, by the joint action of the two, be reduced to a level at the surface of the sea. It is believed that the denuding power of the sea is greatly inferior to that of the atmosphere, and that, while the latter produces the great features of land surfaces, the former is continually striving to efface them, the materials of waste, whether derived from the land by streams or from the shore line, being deposited in the sea bottom in masses which are approximately horizontal. Natural gravity effects a certain kind of arrangement, the heaviest blocks being those which settle first. The succession of marine deposits, theoretically stated as gravel next the land, sand farther out, and mud farthest out of all, is in general terms correct; but a serious difficulty is presented by the fact *that on many coasts,* and especially at the mouths of large rivers, finer grained mud is found close up to the coast line. An ingenious observation of Mr. David Robertson explains the difficulty: he finds that the addition of a small quantity of salt water to fresh water which contains a large quantity of excessively fine sediment, causes the precipitation of the sediment to take place in a very much shorter time than if it were left to itself; hence the throwing down of mud at the mouths of large rivers is the consequence of an alteration in the density of the water, and the rule as to the gradation of deposits, as above stated, is only absolute for the purely fresh water accumulations of lakes.

The materials found upon the floor of the ocean, passing from the ordinary coast line seawards, are coarse sediments, finer sand, and mud—the mud, as a general rule, being found in deep water; but in the very deepest parts of the ocean, as in the Atlantic, the sediment consists almost exclusively of the calcareous oaze derived from the disintegration of the shells of marine animals. Following up the indications thus suggested, Mr. Hull has pointed out that the sedimentary mechanically-formed strata, consisting of gravels, sands, and clay, are inverse in their quantity to the calcareous.



Thus the carboniferous strata of Scotland contain a large quantity of sedimentary beds alternating with the limestone, whereas the calcareous rocks of Middle England are free from sedimentary admixture, and of very much greater vertical thickness, the inference being that deep water prevailed there, while a shallower sea had its shore in the north of Scotland. The carboniferous strata of the Appalachians are chiefly sedimentary, the limestones of the Mississippi basin indicating that a deep ocean lay towards the west, while the land was eastward where the Atlantic now is. The chalk, which finds its nearest living representative in the Atlantic oaze, contains many fossils which were evidently pelagic, he inhabitants of a deep open ocean; while towards the outh of France the formation has a larger admixture of sedimentary materials, and the fossils are chiefly of types common in shallower waters.

22. Disturbances of Sedimentary Strata.—Sedimentary strata, then, consist of masses of material, deposited mechanically under the influence of gravitation, and they are divisible into layers of greater or less thickness, in consequence of the intervals which frequently suspend the process. For sediments are not brought continuously and in equal quantities from the land; they vary with the seasons, and it may happen that by a change in the interior of a country, the amount of waste may either be very much diminished permanently, or very much altered in quality; thus the conversion of a well-watered district into a rainless region would at once cut off a large part of the sediment thus derived, while, conversely, the subjection of a district to a larger amount of atmospheric waste, whether by a change of climate or by the cutting down of timber, as in the Georgian case already referred to, would gradually increase the sediment thence obtained, and might introduce materials of very different character from those previously brought down. Hence it is not to be expected that, under ordinary circumstances, a mechanical deposit in the ocean should attain any very great thickness; we should expect to find that different materials were from time to time brought down, giving to it vertical alternations of materials. It must be borne in mind that the thickest uninterrupted deposits of one kind of material, those, namely, which characterise the old red sandstone, were, as will be shown in a future chapter, probably formed in enclosed basins or inland lakes, and during slow subsidence.

Neither is it to be expected that the same deposit will have an indefinite horizontal extension. As the coast line manifests the same variety, both in texture and chemical composition, as the interior, it is obvious that denudation yields unlike materials at different points. This horizontal variation, dependent in part upon the greater amount of debris brought down from one district than from another, is influenced likewise by the transporting power of marine currents. These have the effect of delaying the settlement of the lighter materials, and of carefully sifting out the detritus *along the shore, so that* the first rough classification by gravitation is revised and made more exact, while, at the same time, the materials are spread over a large area.

To the variation from time to time of the materials, and to the dispersive power of currents, must be added a third influence, namely, that of movements of elevation and subsidence. The most favourable conditions for extensive vertical accumulation of sediments are during subsidence, the least favourable during elevation; but during subsidence the distance of the shore line from the deepest water is gradually increasing, and consequently the limits of particular kinds of materials are altering.

Coast 2. Gravel. Sand. Mud. Oaze.
Coast 1. Gravel. Sand. Mud. Oaze.

In this diagram, Coast 1 represents the position of the margin of a country which is undergoing submergence; Coast 2 represents the distance which the shore line has retreated in consequence of the depression. In general terms we should expect the various deposits to shift their limits shorewards, in the manner suggested by the superposition of the words in the diagram, and thus, while the deposit of mud goes on, actually without interruption, a vertical section would show that, apparently, it had been interrupted, since we find a layer of oaze above it. If, on the other hand, elevation took place, we should find the gravel gradually shifting farther and farther out as the coast line gradually encroached upon what had formerly been deep water, and thus we should have an apparent interruption, as registered in the vertical succession, whereas, in truth, the process of deposit of one material had gone on continuously. The difficulty, therefore, of interpreting the events of former periods in the history of the earth is increased to us by the manner in which the evidence is presented. Sir Henry de la Beche first pointed out that the two extreme points of any one bed were not contemporaneous; that, in fact, to return to the diagram above, part of the gravel, of the sand, of the mud, of the oaze, were laid down at the same time, and that thus our lines of contemporaneous deposit, in the strictest sense of the term, would not coincide with the plains of stratification; the accompanying diagram will make this intelligible.

G	G	G	G	G	G	G			
	S	S	S	S	S	S	S		
			M	M	M	M	M	M	M
1	2	3	4	5	6	7	8		

The letters G., S., M., correspond to gravel, sand, mud, and the figures represent the mode in which these materials are laid down upon the floor of a large lake. It is obvious that, as the lake gradually becomes filled up, the gravel occupying a larger cubic space though a less horizontal area than the sand (as the sand does than the mud), the gravel will gradually creep out towards the centre of the lake, and thus come to repose upon the successive layers of sand which have crept out along with it. While therefore when the lake has been filled up, the gravel occupies one layer, the sand another, and the mud a third, and while the gravel, sand, and mud layers appear to be each later than the other, the latest or youngest being uppermost, the real order of chronology is represented by the oblique lines, G., S., M., and the contemporary in point of time of M. in the sixth column is G. in the third. The broad statement, therefore, that the youngest strata lie upon the older, can only be taken as correct for their general mass, and not as absolute for the individual parts.

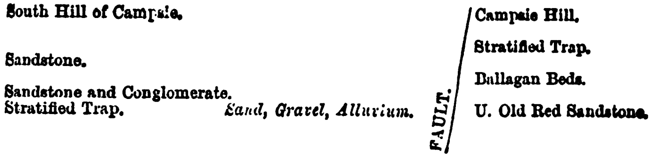
23. Outcrop.—The table of formations given above (Art. 11), represents the order of succession in which the fossiliferous strata are found. It is formed by comparing the structure of different regions together, and generalising the results. But it must be remembered that in no country do we find the succession so complete as is here suggested, and this table does not, therefore, convey an actual picture of what is found in nature. It is, perhaps, impossible to avoid such a general statement, but it is very necessary to keep carefully in mind the fact, that the relations of these different formations may not be truly represented in all cases. The table, as it now stands, represents the opinions of a time when it was thought that all these formations were marine sediments, and when the existence of contemporaneous dry land was disregarded. Professor Ramsay, in his *Physical Geography* of Great Britain, has remodelled the table, and has introduced into it the characteristic conditions of each formation; thus, the cambrian, possibly the old red sandstone, the permian, and the triassic strata are, as will be afterwards more fully explained, probably the records of lacustrine or mediterranean conditions; and, as these conditions are only possible during a continental elevation, it follows that, for a large part of the palæozoic period, in this country at least, land took the place of water, and that the equivalents in point of time—the strict contemporaries of these red strata—are the marine deposits of some other locality. Professor Huxley urges the employment of the word homotaxis to indicate the relations of the successive strata at different points of the earth's surface, and the term is intended to suggest that the successive strata occupy the same relative position to each other wherever they may be found; but that those formations to which we give the same name in distant localities are not, therefore, necessarily of precisely the same age; to compare, for example, the section of the North of Scotland, and that of South America, as given by Mr. D. Forbes:—

Scotland.	*South America.*
Oolitic.	Oolitic.
Old Red Sandstone.	Permian, or Triassic.
Lower Silurian.	Carboniferous.
Cambrian.	Devonian.
Laurentian.	Silurian.

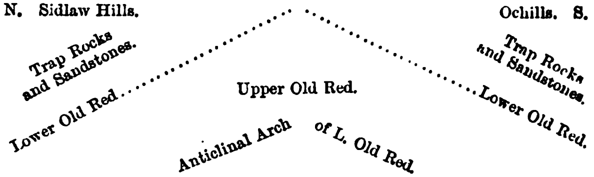
These two sections do not consist of the same formations, nor is it probable that the particular strata to which the same name is applied belong to precisely the same period of time. In the first place, the devonian beds are marine, the old red sandstone of Scotland being, on the other hand, a lacustrine deposit; the carboniferous strata were also marine, their fossils being, some of them, identical, others only similar to those found in this country; volcanic outbursts of considerable importance occurred between the carboniferous and the oolitic period, and the permian or triassic strata have undergone considerable disturbance. The common facts as regards these two countries are: that we have in both the history of frequent oscillations, terminating in a continental condition in this permian or triassic mass, and that, thereafter, depression again took place beneath the water of the oolitic sea. The general resemblance of the fossils is a clue to the general succession of the deposits, and the differences are similar in kind to the differences which exist at the present time between the types of animal life at different parts of the world. If it is not possible to admit of the universal distribution of the same species of fossils over the whole surface of the earth, such distribution being unsupported by analogy, we can only account for their occurrence at distant parts of the earth by their migration. Migration necessarily implies difference in date, and hence the very fact of the resemblance of fossils at distant localities suggests alterations in the physical geography of the period. It is not difficult for us to guess the successive slow changes, whereby the geography of one period assumed the characters of the next succeeding time, but we can only approximately conjecture the kind or direction of the changes. If we could determine them in all cases with precision, we should be enabled to picture the successive phases in the physical history of the earth, and the history of its life would, thereafter, be easy. In support of this view, Barrande's investigations into the fossils of Bohemia furnish valuable evidence; from his researches it appears that, at successive stages in the silurian strata, fossils occur in groups which had been extinguished in that area at an earlier period. This recurrence of groups of fossils would have been impossible, without at least the assumption of a large number of unwarrantable hypotheses, if we believe that when they disappeared from the Bohemian strata, they had been absolutely extinguished. Their recurrence, therefore, is clear proof that, in the interval, they had only travelled into adjacent areas, returning thence when the conditions again became favourable.

The most important points which it is necessary for the student of physical geography to bear in mind are: (1) That the surface of the earth, as it at present exists, presents an inequality and irregularity of distribution of land and water, and there is every reason to believe that this kind of inequality has existed from the most remote past; (2) that, whether by movements of elevation or depression, or by the action of *denuding agents,* the contours of the land surface are becoming modified, and the waste materials are travelling seaward, there to be deposited in stratified layers, which at some future period shall be elevated into the condition of dry land, and again undergo a course of disintegration; (3) that the materials of which these strata are composed vary horizontally and vertically, the variations being consequent upon the difference of the physical and chemical structure of a country, on the difference of movement of the earth's crust, and of ocean currents; (4) that in the past, as at the present time, there were differences in the rate and amount of deposit at various points, and hence the thickness of an accumulation over one area may differ very importantly from that at another; (5) that the time occupied by the deposit of these layers of different thickness may or may not have been the same; (6) that the strata of different localities are classified according to the fossils which they contain, the tables showing that the types of fossils follow each other in every region in the same general order, and that species, even though not identical but merely similar, nevertheless present a parallel order of succession, even in distant localities.

24. Dip.—Sedimentary strata are deposited on surfaces which are, for the most part, nearly level; their inclination is, therefore, at first slight, but they are usually found to incline to the horizon at an angle which may be a right angle, and in some rare cases may pass over so that the inclination becomes reversed, and the originally lower surface may form the upper surface in the new position. The inclination of the beds to the horizon is the dip, and the direction of the edge of the bed when it cuts the ground is the strike; dip and strike are, therefore, at right angles to each other; they coincide when the bed is quite horizontal, and the dip disappears when it is perpendicular. The edges of strata are truncated, the face they present being more or less abrupt; for the effects of denudation depend on the speed of the process, and the texture of the strata. The amount of materials that has been removed may often be guessed by help of the dip, the planes of which, when produced, give some idea of the former extension of the strata. Thus the Strathblane valley gives the following section.



These beds of the Campsie Hills would, if produced, lie above the South Hill, but their true position is below that hill, the fault having disturbed their relative positions. The valley itself, however, is excavated out of the sandstones and traps, which have gradually been worn back on either side, their edges of outcrop becoming more and more sloping. The transverse section of the Tay valley is that of a broad trough, which is partly filled with upper old red sandstone beds, while floor and sides are of lower old red sandstone and trap rocks, which the river, in remote times, had denuded prior to the deposit of the upper old red.


N. Sidlaw Hills.
Ochills. S.
Trap Rocks and Sandstones.
Lower Old Red.
Upper Old Red.
Trap Rocks and Sandstones.
Lower Old Red.
Anticlinal Arch of L. Old Red

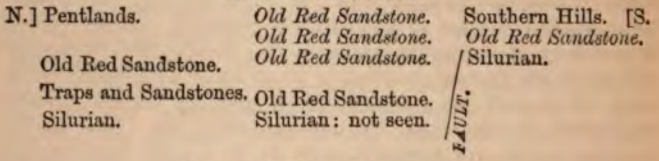
If the lines of the strata on either side were produced as shown in the dotted lines, it would become apparent that a conical mass had been denuded away, the quantity then removed being capable of calculation from the known thickness of the beds on either side. The horizontal strata in the middle rest on the denuded edges of beds which had been bent into an anticlinal arch. The valley of the Tay is, therefore, a geographical valley, but a geological hill, and the upper is violenty unconformable on the lower old red.

25. Curvature.—Elevation and depression of limited tracts of country, accomplished with more or less violence and suddenness, give the simplest form of disturbance by which sedimentary strata are removed from their original horizontality; for the limited elevation gives a dome or a ridge, from the centre of which the beds dip away. If the dome becomes denuded by sea and atmosphere, and thereafter is submerged so as to be covered with marine strata again, unconformity is the relation between the older and newer deposits. This relation is shown in the diagram given above, and in those in Art. 11, and it indicates that a period of time of unknown length has intervened between the dates of the two deposits. The occurrence of such unconformities between formations shows that there has been a great change in the physical geography of the district, and that this change has been great enough, and the time long enough, to allow the plants and animals of the earlier period to remove, and either to return modified in form during their migrations, or to be replaced by a new set of organisms coming in from some other locality. The curvatures are usually, however, more complicated than in the case first supposed. Several adjacent elevations form a succession of anticlines with intervening troughs or synclines, and in rare cases, as the Appalachians and the Jura, these features correspond to the features of the ground, in place of being reversed, as in the case of the Tay valley. The amount of folding to which the strata have been subjected varies much; a few broad undulations, for example, form the Thames valley and the Solent, the intervening ridge having been denuded into a valley, the Weald like the Tay occupying the site of a geological hill. In the silurian districts, on the other hand, the strata are thrown into many narrow curves, and in these subordinate crumplings abound.

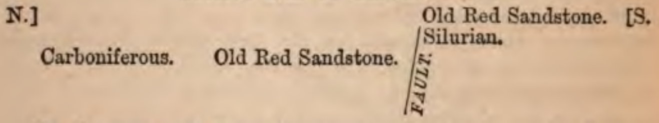
26. **Faults.**—The curvature of the rocks in a district is usually in the inverse ratio of the fractures which the strata have sustained. Fractures are of two kinds, both traceable, however, to the same cause. All rocks, at least all of any density, are traversed by joints, are intersected by division planes, which, when well developed, cut up the rock between the planes of stratification into cubes. These joints facilitate the work of the quarryman and miner, the "face" of the coal making the process of extraction also more economical than it would otherwise be. This kind of structure is due to pressure, and is essentially the same as the cleavage of slate already referred to. The fracture with displacement constitutes a fault, such as is illustrated in the section of the Strathblane valley. The rocks have been broken, and one

side has slipped past the other, so that corresponding portions come to lie at very different levels—the trap in that particular case forming the top of one hill, and occurring far down in the opposite hill. The amount of displacement, what is called the throw of the fault, varies from inches to thousands of feet, and the distance to which they may be traced is equally varied. But in tracing a fault line for enormous distances, as in tracing a volcanic chain or an earthquake movement, it does not necessarily follow that only one movement has determined the whole: the probability that there were several increases with the length of the fault, and more than one parallel fracture line may become united. The inverse relations of faults and contortions of the strata have been ingeniously explained by Mr. J. M. Wilson, who points out that if a portion of the earth be elevated, and thus come to occupy a greater horizontal area than it did before, it cannot return to its former position so as to leave everything as it was. The rock has been displaced, and the earth's surface is curved; hence, when the area subsides, the rocks would become folded on themselves so as to occupy the former space, and contortion would thus be due to subsidence of a curved surface, while elevation might occur in an adjoining district, so that the strain in the first would be relieved. But if, during elevation, the convex surface of the mass becomes fractured by the strain, subsidence may be accompanied by the relative displacement of the portions on either side of the fracture line, and thus the whole might be again accommodated within the former area without contortion, and without compensating movements in adjacent districts. Faults, like the metamorphosis of sedimentary strata, and the fusion of igneous rocks, are doubtless in progress at the present time: great elevations, as that of the Chilian coast, extensive subsidences, like those of Greenland and of the Aralo-Caspian area, cannot have left the strata unaffected; and geologists have shown that the smooth surfaces of rock on either side of faults are scratched or scored in such a way as to indicate that the displacement has been effected by several movements at different periods, and not always in the same direction. The gradual development even of a displacement to the extent of 2000 feet, is one of the reasons why faults are not indicated at the surface by any prominent features. Even had the dislocation been sudden, denudation would in time have smoothed away the outstanding portion; still more would denudation efface the asperity of surface resulting from a gradual downward movement. But fault lines do sometimes coincide with the wall of a valley for a considerable distance. Thus the northern boundary of the silurian hills of South Scotland is to a large extent in a line of fault. In the subjoined diagram, the names in Roman letters represent the present surface; those in italics occupy the place of the strata removed since the full development of the fault.

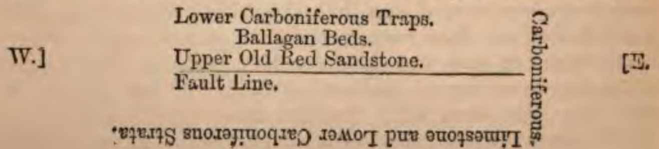
SECTION AT BIGGAR.



SECTION S.E. OF HADDINGTON.

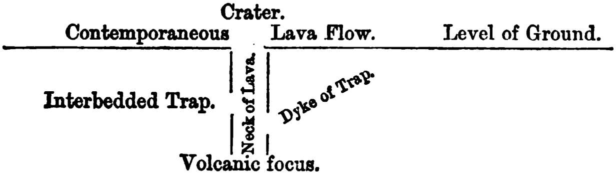


In the upper of these figures, the italics show the former relations, the old red sandstone having once covered the tops of the silurians. Near Biggar, the silurians are now bare; but to the N.E. the old red is still found in patches on the silurians. The relative displacement near Biggar is very much greater than near Haddington; but the tapering form of a fault line is perhaps best suggested by a ground plan of the Campsie district, from Stirling westwards. The



fault line dies out eastwards; and the carboniferous limestone, which, west of Stirling, is found only on the south side of the line, is there found on both sides of it, forming a continuous sheet across.

27. Contemporaneous and Intrusive Igneous Rocks.—The relations of the igneous rocks will be discussed in a future chapter; but it may be mentioned here, that by contemporaneous trap rocks are meant those sheets of lava which have been poured out at the surface *on* sedimentary strata, and which are afterwards covered by other sedimentary strata, while the rising column of molten rock, which overflows at the surface, is an intrusive neck which breaks through sedimentary strata. But as this column ascends under pressure, portions of it may force their way between subterranean strata, or into the vertical fissures which may traverse them. Thus a single volcanic outburst would, if we could see the whole course of the molten matter, illustrate all these phases. The subjoined diagram will suggest the relations—the space below the horizontal line being occupied by stratified deposits:—



The contents of rocks, apart from their essential components, are mineral substances which are segregated after their consolidation, and organic remains, or fossils. The former are the province of the mineralogist; the latter are the materials with which the palæontologist has to deal.

28. Preservation of Fossils.—The remains of plants and animals are either preserved in the places where they lived, or are drifted to other localities, and there preserved. The completeness of the remains depends on the rapidity with which they have been covered up, or on the process to which they have been subjected. The mammoth was frozen into the Siberian cliffs, and the bodies, untouched by decay, were perfectly preserved till our own time; men and animals buried in peat have been found, shrivelled but entire, and the tissues, deprived of their moisture, may be perfect if the body has been exposed to great heat in a dry atmosphere. But for the most part decay has set in before the object is covered up, or goes on afterwards; in the latter case, we should expect to find the whole of the hard parts preserved in their natural relations; in the former case, the amount which comes down to us depends on a variety of circumstances. Thus, shell fish dying in great depths of water will slowly decay, and only the hard shells be covered up; but the shells may, in a sandy material, subsequently disappear, infiltration of water charged with carbonic acid dissolving the calcareous matter; and this action usually goes on in fresh waters before the shells are covered up, so that only a layer of marl represents perhaps a very abundant molluscan fauna. If the mollusc dies within reach of the shore waves, it may be rolled to and fro till it is ground to powder, as if it were a pebble. Animals dying on land are either eaten up by other animals, or decay disintegrates even their skeletons, while the hardest parts may be washed into rivers, rolled to and fro, and finally entombed in a very mutilated state. If the carcase is at once carried off by a stream, it may be partly devoured as it floats, and fragments of the skeleton may thus be dropped at intervals, leaving curious puzzles for the zoologist. Icebergs every year float from the extreme north, carrying away Arctic animals which could not escape, and whose remains are scattered over the sea floors of temperate or even sub-tropical regions. Dr. Buckland experimentally demonstrated the reason for the comparatively large number of lower jaws of vertebrated animals contained in fossiliferous strata. These bones have very slight attachments to the trunk, and drop off therefore easily. If we knew the *exact* equivalents in time of the jaw-containing strata, we might find the remains of their skeletons, and thus combine into one parts which, in their fragmentary strata, have been referred to different genera. Large numbers of animals are sometimes found entombed together, killed probably in shoals by floods of fresh water poured into the sea, or by outbursts of springs charged with noxious substances; these two phenomena having occurred in recent times in the Bay of Fundy and in the Indian Ocean. The Pampean mud contains vast quantities of mammals which have sunk in the swamps, and been trampled down by those which followed, eager to drink after-droughts. Of animals which contained no firm parts, no remains can be expected to survive; yet even of the gelatinous jelly fishes or medusæ, the casts have been preserved in soft sediments with sufficient perfection to allow the zoologist to determine their affinities. But these are exceptional cases, and the paucity of the remains of inferior invertebrates is doubtless due to the extreme softness of their tissues. The zoologist, therefore, is deprived of an important kind of evidence on which to rest his speculations as to the succession of life. The tissues may be preserved, retaining their original chemical composition; but they may undergo metamorphism, thus the carbonate of lime in stone lilies and bivalve shells may be crystallized in the characteristic rhombs, the form of the shell being retained. The material may entirely disappear, being replaced grain for grain by other matters: thus plants and animals may show all their finest structure in silica, or the structure may be lost while the form is intact, if grains of sand have taken the place of the organic substances.

The value of fossils is twofold; they may serve as guides in the identification of particular strata, the definiteness of their forms giving them high value for this purpose; or they may afford the biologist the means of filling up his scheme of the classification of plants and animals, their study being then an integral part of botany and zoology. The interpretation of fossils, then, is not a mere mechanical process, but depends for its value on thorough knowledge of the nearest living kindred of the extinct forms. The general tables of the succession of fossiliferous strata were based for the most part on the more mechanical investigation of fossils. But fuller knowledge has shown that tables so constructed do not tell all the truth. Thus it is quite correct that the silurian strata contain fossils on the whole distinct from those of the old red sandstone, still more distinct from those of the carboniferous. But Professor Ramsay has pointed out that even the subordinate members of the silurian series are separated from each other by gaps of great importance. He has tabulated the silurians as follows, from above downwards:—

WENLOCK SHALE.
  Break and strong unconformity.
UPPER LLANDOVERY BEDS.
  Break and decided unconformity.
LOWER LLANDOVERY BEDS.
  Large break, especially in species, and probable unconformity.
LLANDEILO AND CARADOC BEDS.
  Break very nearly complete, both in genera and species, and probable unconformity.
TREMADOC SLATE.
  Break very nearly complete, both in genera and species, and probable unconformity.
LINGULA FLAGS.

Great differences in the fossil contents of two successive groups of strata are, in some cases, associated with unconformity, and this, as has been explained, means repeated movement of the inferior mass of strata with some amount of denudation, the whole representing the lapse of a considerable period of time, and a correspondingly great change in the physical geography of the region. Again, he has shown that the lower greensand contains 280 species of animals, of which 233 are peculiar to it, while 57, or 18 per cent., are found also in the upper cretaceous. Unconformity accompanies this great break in the succession of life, and the 182 species not found in England migrated, or were destroyed by the geographical change. Again, the occurrence of recognised terrestrial conditions in this and other areas, as during the cambrian, old red sandstone, upper carboniferous, part of the permian, trias, weald, and eocene times, presents so many interruptions in the succession of the marine life, on which our classifications were almost exclusively based.

What, then, is a formation? The evidence points in the direction of an important change in our conception of that phrase. Whereas, formerly, the idea of time was inseparable from it; whereas, formerly, a formation meant a group of deposits laid down during a particular period, and the next overlying formation laid down during the succeeding period, the observations and speculations of Godwin Austen, E. Forbes, Huxley, and Ramsay, on the older rocks, and the remarkable results obtained by Carpenter, Wyville Thomson, and others, in deep sea soundings at the present, indicate what may be called an overlap of formations, the most obvious consequence of which is that they no longer represent a perfectly definite chronology. The principle has already been conceded by the Geological Survey of the United Kingdom in the case of the old red sandstone or devonian, for these formations are thus arranged on the table published by that department:—

Carboniferous.

Scotland.	*Hereford and South Wales.*	*Devonshire. Marine.*
Upper Old Red Sandstone.	Upper Old Red Sandstone.	Upper Devonian.
Middle Old Red Sandstone.	Lower Old Red Sandstone.	Middle Devonian
Lower Old Red Sandstone.		Lower Devonian.

Silurian.

Two perfectly distinct kinds of sediments and types of animals, represent two perfectly distinct geographical areas, the one continental, the other marine, which co-existed during the interval between the silurian and the carboniferous; we have here, therefore, a good case, illustrating the general proposition that formations represent geographical areas, not periods of time. Again, the wealden land existed before and after the set of deposits, which now preserve its debris, were laid down, and the fact might be represented in a table, thus:—

Tertiary.

Wealden Land.	Upper Cretaceous.
Purbeck Land.	Lower Cretaceous.
	Jurassic.

The wealden land merged into the tertiary, just as it was itself the direct continuation of the purbeck land; or again, to take marine deposits:

Existing Seas.	Existing Continents.
Cretaceous Seas.	Tertiary Continents.
	Wealden Land.

It may be a long time yet before the details of these relations are elaborated. But it is right to set before the student such a general view as may enable him to understand the drift of modern investigation, and to appreciate the connection which exists between the geography of to-day, and the geography of former periods.

CHAPTER II.

SECTION I.—CONTINENTS.

Their Areas—Homomorphism—Coast Lines: their Homomorphism; Mountain Chains Parallel to Coast Lines—Evolutions of Continents: Great Britain; North America—Persistence of Deep Oceans—Theory of an Insular Period—Influence of Variations of Land and Water Surfaces on History of Man.

THE surface of the globe is divided between land and water, the latter covering an area nearly three times as large as that of the former. The approximate measurements for the land being 51 millions of square miles, for the water 146 millions of square miles, makes the total area of the globe 197 millions of square miles. The ratio, on this calculation, is 1 : 2·8; the proportion given by Sir Charles Lyell, on Mr. Saunders' authority, is 1 : 2·42.

29. Areas of Continents.—The land is irregularly distributed: 1° The greater mass is found in the northern hemisphere, and in that portion of it which lies between 40° W. lon. and 150° E. lon., the area thus indicated including the European and Asiatic masses. 2° The great blocks of land have their northern extremities massive, while they taper towards the south. 3° The mean elevation of the continents follows generally their horizontal dimensions. The following table gives some of the measurements adopted by various

	Average Height.			Area in Square Miles.			Coast Line.	
Europe,....	670	630	1010	17,290,000	14,128,000	17,600,000	30,800	33,000
Asia, ...	1150	1080						
America,...	930	876		16,000,000	10,608,600	14,000,000	47,600	44,500
Europe,....	670	630		3,550,000	2,688,000	3,400,000	17,200	20,000
Africa,,....	1600			11,511,000	8,720,000	11,300,000	14,000	16,500
Australia, ..	500			3,413,000	2,208,000	3,500,000	7,600	7,600

writers; they are thus tabulated to show the range of variations between calculations, which are, after all, mere approximations.

Inspection of a map or a globe will show that the land and water are inverse to each other in ratio as well as in form in the two hemispheres. All the continental masses, including Australia, have their greatest breadth towards the north, and this tendency is apparent even in both divisions of the American continent. Hence the northern circumpolar land may be said to be prolonged in wedges southwards, while the great water circle of the southern hemisphere presents corresponding alternations towards the north.

30. Homomorphism.—The similarity in form of the continental masses is one of those resemblances which have been spoken of as geographical homologies; but the importation into geography of this anatomical phrase is unfortunate, since we are not yet in a position to affirm that the forms have been impressed in all cases by the operation of the same law, however probable it may be; and we know that neither in point of age nor geological structure, are the continents identical. As, however, a compendious term is required to express this relation of similarity, homomorphism is less open to objection, and it is used in the following pages because it implies no theory, and would still continue applicable even if a uniform cause were demonstrated.

31. Coast Line.—The greater breadth of continents at their northern extremities, and their attenuation southwards, are obvious, and are carried out even in considerable detail. Thus N. America and S. America repeat the same figure: in both the eastern shoulder projects, culminating in Cape Charles in Labrador, and Cape St. Roque in Brazil. Africa projects westward, the coast line between 10° and 30° N. lat. overhanging the Gulf of Guinea. Thus the S. Atlantic basin is bounded by two masses of symmetrical form, save that their leading features are not under the same parallels of latitude. The Red Sea separates Africa from Arabia, and the latter country is again separated by the Persian Gulf from Persia. Arabia, moreover, has a north-westerly angle, the Muscat peninsula, which repeats the Somali prominence of Africa, so that the entrances to the Red Sea and the

Persian Gulf present the same angular form. Cape Comorin terminates a triangular area, which the valleys of the Indus and the Ganges nearly separate from Central Asia, and the Malayan peninsula gives numerous examples in detail as well as in its general form of the same triangular shape. Australia is at present separate from Asia, but there is sufficient evidence that this separation is of comparatively recent date, according to the geological standard of time, though in the ordinary language of men it is of very remote antiquity; and, bearing this in mind, it is clear that the Pacific Ocean is in reality bounded by two homomorphic masses, the main axes of which are parallel, the Central American isthmus finding its counterpart in the isolated lands of Sumatra, Java, and Timor. The axes of these masses—not the leading mountain chains, but the lines equally dividing their area—are meridional, those of S. America and Australia curving westwards, N. America and Asia eastwards. Europe is exceptional to what at first appears the rule, that the northern and southern masses have contrary inclinations, since that mass of which Spain is the south-western extremity has, at least at present, its axis convergent with that of Asia. Other exceptions are found on a minor scale, the land pyramids of the northern Mediterranean shore having their axes irregularly disposed, and rarely meridional. The homomorphism of land masses then, striking as its leading features are, cannot be maintained as an absolute rule. The exceptions are due to the irregular lines along which those influences acted to which the form and character of the coast line may be traced; and in the coast lines of various countries homomorphism of another kind may be detected.

The extent of coast line of the principal masses of land has been stated in the table, Art. 29. Not much importance can be attached to these figures from a theoretical point of view. The configuration of the coast depends upon the geological structure of a country, upon the length of time during which it has been exposed to denudation, upon the uniformity or variety in hardness of the rocks, on the influence of prevailing winds and marine currents, the amount of rainfall, or the presence of ice—in short, on all those circumstances on which depends the wasting or denudation of the dry land. The uniform outline of Africa and Australia is analogous on a large scale to the configuration of the east coast of England, where the sea line, being formed of rocks comparatively homogeneous in texture, shows notable indentations only at those points where streams reach the sea from the interior. Again, the serrated coast lines of Norway, West Scotland, and Ireland, and of western S. America, tell not merely of similar conditions as regards atmospheric waste, meaning thereby the influence of rain, rivers, and ice, but also of similarity in the texture of the rocks themselves, which are, in all these cases, highly disturbed and altered strata of unequal hardness, and disposed in layers at considerable angles, often at right angles, to the horizon. The characters of the coast line are those of the general surface of the country; a generalization which only expresses in other words the fact that the features of the sea bottom are those of a former dry land now submerged. This relation of the submarine valleys to those of the dry land will be more evident when the origin of valleys has been discussed; meanwhile the student may satisfy himself, from the atlas, that the intervals between the islets off the coast of N. and S. America, of Norway, Scotland, and other countries with similarly rugged outlines, may be referred to prolongation of the river courses of the dry land.

32. Mountain Chains Parallel to Coast Line.—Considerable importance has been attached by geographers to the fact that, in a large number of cases, the leading mountain axes are close to and parallel with the coast lines. Thus, the American continent is traversed by a nearly continuous line of mountains; Scandinavia has its line of heights towards the western shore. The margins of the S. African central basin are elevated; the Australian highest grounds are on the eastern shore. But the exceptions are more important: thus, the European Alps have no obvious relation to a coast line; the Himalayas are far from the sea; the transverse chain which, there is good reason to believe, traverses Equatorial Africa, is neither close to nor parallel with any adjacent shore at the present time, though it was close to the margin of the geologically recent Sahara Sea. The position of the highest grounds is for the most part capable of explanation by reference to the geological history of a country; for, though it is not in all cases possible to follow the evolution of the continents, still a few instances occur in which the course of events is tolerably clear.

33. Evolution of Continents.—On the geological map of the British Islands (*Student's Physical Atlas*, Pl. XX), the bands of colour which represent the formations have considerable regularity. The oldest rocks, the laurentians, are found in the north-west in the Hebrides, and these are themselves formed out of the debris of pre-existing dry lands, whose position, however, we cannot positively determine. Probably it was to the west and north-west, in the position of the present Atlantic basin. This at least is certain, that the next succeeding formation, the cambrian, lies in hollows on the surface of the laurentian, and that these together formed the floor and shore, on and against which the silurians were deposited eastwards and southwards. The inland seas of the old red sandstone represent another elevation of the sea floor along a N.E. and S.W. line, the regularity of which is, however, broken by the valleys, into which rain and rivers had fashioned the plain of marine denudation, and the semi-continental area had on its south shores the seas in which the devonians of S.W. England and Germany were deposited. Prior to this time, by inequalities of movement and by denudation, the silurians had been divided into isolated masses, those of Scotland forming three bands, imperfectly parallel: the one to the N.W. of the Caledonian Canal; the next the wedge whose apex is seawards towards Donegal Bay, and which is separated by the broad middle valley of Scotland from the southern uplands. This silurian mass has its axis prolonged into Ireland, and the hog-backed ridge it presents sinks down to the N.E. and S.W., and is there covered by the later formations. But already Scotland had undergone more elevation than England, for the upper silurians, which in England had been laid down around the emerging lower silurians, are not found in N. Scotland, and, in the south, fringe the great bank of land just mentioned. At the Pentlands, S.W. of Edinburgh, at Lesmahagow and Girvan, on the north side of the lower silurian tract, and near Kirkcudbright on the south, the upper silurians rest unconformably on the lower, the latter having therefore been disturbed and elevated—perhaps they even formed an island—before the deposit of the former. The slow submersion and re-elevation of the area during carboniferous times, did not disturb the relative heights of the two countries; at least the marine carboniferous rocks of Scotland have more the character of shore and shallow water deposits than those of England. After the partially continental condition which characterised the close of the palæozoic and the commencement of the mesozoic periods in this area, there is a steady change in the axis of elevation of the shore line, and the colour bands describe a curve the convexity of which is towards the S.E., while the axis of the tertiaries is east and west, as are the axes of the latest elevatory movements in this part of England. In general terms, therefore, the land has grown towards the S.E., and the hill ground on the west has come to border the coast line, because the lower ground in that direction has partly subsided, and partly been removed by denudation. A similar history of development is furnished by the eastern portion of the N. American continent; but though the laurentian rocks, the first sedimentary deposits formed on the shores of unknown lands, form a much more complete series, the rocks subsequent to the carboniferous are not so varied as in Britain. The thick sedimentary strata of the Appalachians contrast with the thick limestones on the west of the Mississippi basin, and indicate the position of land to have been out towards the Atlantic. But though this ocean was formerly the site of extensive dry land, it does not follow that it ever formed one continuous continent. The probability is, that the changes to which reference has been made left a central valley always under water, that the shores of the ocean have advanced and receded, but never effaced the intervening trough. Palæontology and physical geology agree in maintaining the all but certainty of a continuous land having connected S. Africa with N. Europe since the trias. The peculiar reptiles are of the same types, and the necessity for them of a land surface on which to pass from the one to the other locality, has compelled investigations which have resulted in the above-stated conclusion. But it does not follow that the land was as continuous as it is now; the shifting of the continent may have been slow, but the migration has been permitted, perhaps compelled by it—just as in more recent times, the shifting land of the Pacific has isolated the Tasmanian, who could not even build a raft, from his kindred in New Caledonia. The land on which the trees and the gigantic lizards of the weald flourished stretched from western England across Biscay into S. France, and the chalk ocean deep to the north shoaled as it approached the Pyrenees.

34. Insular Period.—Conjectures have been formed as to a former insular condition of the northern hemisphere during the carboniferous period; but it is now satisfactorily ascertained that the facts of that period are more intelligible on the theory that the land was continuous, and that the archipelago of small islands assumed to have existed would have involved a departure from the known proportions of land and water, for which there is neither proof nor analogy. In his *Principles of Geology*, Sir Charles Lyell gives a map showing those parts of Europe which have been under water since the commencement of the tertiary epoch. It appears that very little of Europe has been dry land through all that period; but the relations of existing to fossil species of animals show that the dry land has for a long time occupied the same general area. In S. America the same relation holds, for the edentates of the present day are the representatives of the gigantic sloths and armadilloes of the latest deposits, and the more recent fossils of New Zealand and Australia belong to the same peculiar types which now inhabit that area.

To admit the extreme antiquity of continents, and to believe that the land and water have always exhibited the same general proportions, does not necessarily involve denial of the possibility of other distributions having existed in the remote past; but the doctrine of uniformity requires proof of any departure from the ratios which, so far as our knowledge goes, have existed from the beginning of the fossiliferous strata; and the doctrine of evolution, which is only a particular case of the law of uniformity, leads us to seek in the geological changes of the past an explanation of the geography of to-day, though we may not always be able to trace all the steps. The existence of the Atlantic as a deep water area, at least since the chalk formation, is one of the things proved by the N. Atlantic exploring expeditions, and the characteristic forms of the Atlantic oaze have been recognised by Gümbel in limestones of the palæozoic period.

35. Influence of Variations in Land and Water Surfaces on History of Man.—The importance of the facts mentioned in this chapter is considerable as bearing on the history of man. The greatest amount of dry land is situated in the temperate regions, which are thus occupied by the most active members of the human race, to whom they yield the most abundant supply of animal and vegetable food, climate and soil permitting the adoption of methods of continuous cultivation impracticable in warmer regions. The coincidence in the temperate regions of the chief subterranean stores of iron and coal, has further contributed to render these areas the most important in the history of the world, since they are at once the chief seats of commerce, and are in possession of the means of conveying their wares, and of producing the arms by the use of which the spread of commerce and civilisation is accompanied. The continuity of the Europeo-Asiatic continent permitted the uninterrupted spread of the various families of mankind, and their almost universal diffusion over the whole area has reduced to very small dimensions the tracts occupied by the comparatively uncivilized peoples of the extreme north and north-east. The isolation of the southern continental masses, on the other hand, has helped to maintain the tribes living in their southern extremities in a state of low civilisation, the condition of the South Africans and the Tasmanians being alike extreme cases—the one being cut off from his northern neighbours by tracts of desert land, the other by a sea which he had not the means of crossing. It must of course be borne in mind that between the northern and southern peoples constitutional differences exist, but these do not explain all the facts for which physical conditions supply the necessary key.

The intersection of the coast line by numerous indentations, as in Scotland on the small scale, in the Mediterranean on the large, helps to diminish the distance of the interior from the sea, and to render intercourse easier. Where, as in the West Highlands, neither the soil nor the people were adapted for commerce, the natural features only made clan warfare easier; but the northern shores of the Mediterranean rendered possible the creation of the vast empires, rich in commerce, and powerful in war, the ruins of which are still grand.

Thus the geological structure of a country, its antiquity as a continent or part of a continent, and the nature and amount of the external influences to which it has been exposed, have an important influence on the history of man.

SECTION II.—ISLANDS.

1° Islands—Dismemberment of Continents—Australia—Malaya—Polynesian Islands—Great Britain — 2° Islands, directly or indirectly due to Volcanic Action — Coral Islands — Reefs—Barriers, and Atolls — Volcanic Islands — Submarine Gravel Banks.

36. Definition.—The distinction between continents and islands is arbitrary, both being masses surrounded by water, and inequality of size does not constitute a true difference. The artificial character of the distinction is further apparent when chains of islands, as the Hebrides, even Great Britain and Ireland themselves, New Zealand, New Caledonia, and New Guinea, at the Antipodes, are found to be successive dismemberments of the adjacent larger masses of land. The elevation of a limited portion of land till it projected above the surface of the sea would constitute an island, which, though still—as a matter of definition—in the same category with a continent, belongs to a different group from the isolated masses formed by the ordinary dismemberment of parts of a coast line. It has been proposed to separate islands from continents by reference to the form of the surface, a continent being a land mass, with an inner basin, like Africa or Australia. But this is practically to make an exception the rule. The African continent exhibits an unusually large area, for its size, of horizontal strata, and the denudation of these has left a central basin, by processes which have occupied long periods, but of which we do not know the details. The disturbed strata of the British Islands and of Canada, though equally ancient as continents, have not assumed a basin form, which, indeed, was incompatible with their structure.

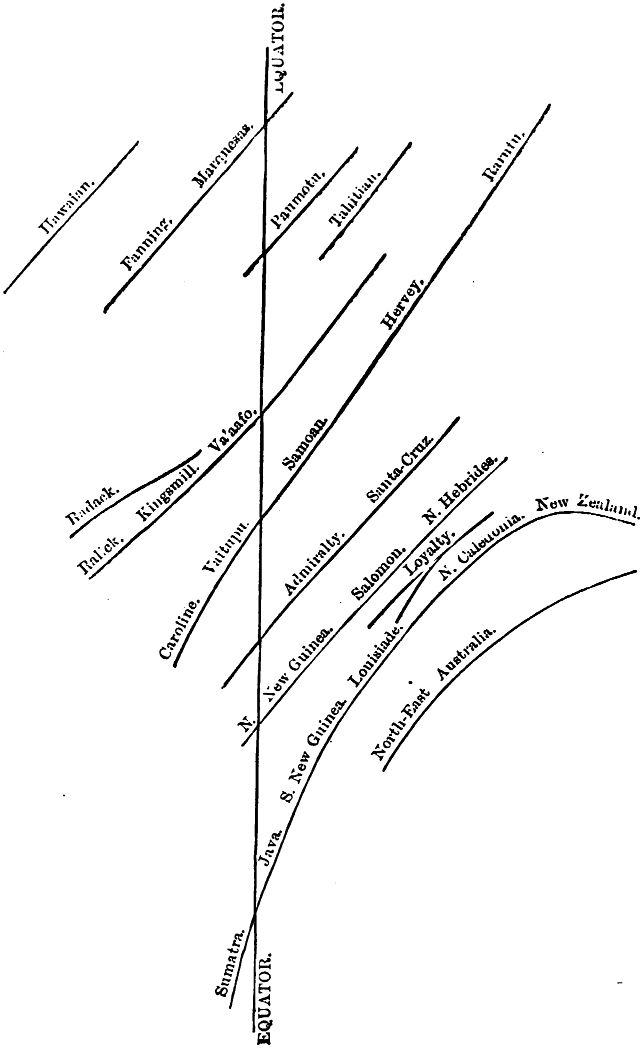
37. Classification.—Islands fall naturally into two groups, those which have been part of continuous land, and those which have a different origin. It is anticipating what will be said in a following section, but it must be premised that the contour of the surface of the dry land is prepared either by movements proceeding from the interior of the earth's crust, or by operations taking place on its surface, and these two phenomena find their extreme illustration in the development of islands.

The two groups are—1. Islands which were once portions of continental lands. 2. Islands which never were portions of continents, but which may become associated with them by extension of the mainland.

38. Islands once part of Continents.—The first group embraces a very large series, the majority of existing islands, which are capable of an approximate chronological classification by reference to the plants and animals they contain. Thus, Australia represents a very ancient separation from all other lands. The animals which it contains, marsupials, ornithorhynchus, and echidna, once had a much more extensive diffusion over the globe, their fossil remains being found in the mesozoic strata of Europe and America. At present, the opossum family (*Didelphidæ*) are the sole representatives of the marsupials beyond the Australian area, and they are found in the Southern States, in Central America and the north part of South America. The remaining orders, the ornithorhynchus and the echidna are confined to that area which includes New Guinea, New Caledonia, New Zealand, Tasmania, and Australia. If, on the map, a line be drawn from the N.W. extremity of Celebes to the N.E. extremity of New Zealand, and if the axis of the latter be prolonged to intersect a line drawn from Adelaide on the south coast of Australia, so as to touch the western shores of Tasmania, a pyramidal area, with its apex at the Macquarie

Islands, will be described, which corresponds to the position and form of a continental mass, similar to the Africa of the present time. The north-western boundary of this continent would be formed by a line connecting Celebes and Western Australia, and passing through the strait between Lombok and Bali. Of this continent, the islands included within this area would be the surviving representatives, while many of the islands lying to the north and east of the limits here given ought, probably, also to be included The definition of this ancient continent is based by Wallace on the distinctness of its fauna from that of the immediately adjacent Asiatic continent; and if we take into consideration the resemblance of the land and marine forms of this region to those of the mesozoic strata of Europe, good reason will be found for accepting his conclusion that these South Pacific Islands are the fragments of a continent which occupied an extensive area at a time when an open ocean occupied the place of South-Eastern Asia. On the other hand, the deep-water sea channel which skirts the western shores of Celebes and Lombok has, on its western side, a group of islands, the animals of which manifest the closest agreement with those of Asia, and prove their recent separation from that mass of land. A plan is subjoined of the Malayo-Polynesian Archipelago, for the purpose of showing the leading lines of the insular groups, lines which may yet prove to have been determined by the leading features of the earlier continent from which they became detached. The lines curve eastwards in Java, Sumatra; and though these islands lie to the east of that ancient deep channel fixed by Wallace, it is important to note that the outline from New Zealand conforms to the lines of high ground in Eastern and Central Africa.

Madagascar, though separated from Africa by a channel of only 300 miles in width, has a fauna so peculiar as to suggest the extreme remoteness of its separation from the adjacent mainland; while Britain agrees so closely with Europe in its animal and vegetable inhabitants as to suggest, independently of other evidence, its recent isolation. Further, the common characters of the types of life found on its western shores with those of Scandinavia, on its south-western portions with those of the Iberian peninsula, and on


EQUATOR.
Hawaiian.
Fanning.
Marquesas.
Paumotu.
Tahitian.
Rurutu.
Hervey.
Radack.
Ralick.
Kingsmill.
Va'aafo.
Samoan.
Vaitupu.
Caroline.
Santa-Cruz.
Admiralty.
N. Hebrides.
Salomon.
Loyalty.
N. Caledonia.
New Zealand.
N. New Guinea.
Louisiade.
S. New Guinea.
North-East Australia.
Java.
Sumatra.
EQUATOR.

its eastern shores with those of Central Europe, suggest not merely a recent, but a direct connection with the various regions named; and an inspection of a submarine chart informs us that the United Kingdom projects from a submarine plateau less than 100 fathoms in depth, the limit of which extends from the north coast of Spain, round and beyond the west coast of Ireland, the Hebrides, and the Shetland Islands, passing thence to the Gulf of Christiania, and skirting the Norwegian coast to the north (*Student's Physical Atlas*, Pl. II.). Physical and zoological evidence thus concur in demonstrating that Great Britain and Ireland are islands recently detached from the mainland. Applying the zoological test, the greater difference of the fauna of Corsica and Sardinia from that of France, indicates a greater antiquity for these islands than for Britain, and thus a graduated scale may be constructed between Britain, in which the variation of species is slight, to Ceylon and Tasmania, in which the number of peculiar forms is progressively greater.[1]

39. Islands Directly or Indirectly Due to Volcanic Action.—The second group of islands includes two distinct types, those which are obviously of volcanic origin, the rocks of which they consist being volcanic products of various ages, and those which are indirectly due to volcanic action.

The Coral Islands of the Pacific Ocean may be taken as the most convenient illustration of the latter class. The general conclusions to which their study by Darwin, Dana, and others leads, are, that the coral reefs are very slowly built up, the growth being estimated variously from $\frac{1}{33}$ of an inch to $\frac{1}{100}$ of an inch in the year. Allowing for the important help given by shell fish and other marine animals with calcareous investments, $\frac{1}{16}$ of an inch is a large estimate, and gives one foot in two hundred years. But as the zoophyte, which secretes in its walls the limestone skeleton, requires a certain depth of water, of which the lowest limit is, on an average, twenty fathoms in the open ocean (though a greater depth is possible in warm waters, as of the Red Sea) to enable it to live luxuriantly, and as the species have very different limits of depth, it follows that the coral may continue *growing only* so long as any change which may take place in its relative level is very slow, a sudden elevation or depression being fatal to it. The presence of great coral reefs on dry land, as in Florida and the Ladrone Islands, indicates the elevation of the surface on which the mass grew; and taking coral debris, not coral reef, as the test of elevation, a relative change of level is certain if the debris is found in quantity at and over twenty feet above high tide mark, that being the general limit of storm-heaped accumulations. That depression has occurred is proved by the separation, by a deep and wide channel, of a coral reef from the island to which it is attached, by the existence of atolls, and by the discovery of atolls beneath the surface of the sea. The atolls or lagoon islands are more or less complete circles of coral reef surrounding a basin of salt water, in other words, representing a barrier reef, the island round which it grew having gradually sunk and disappeared, while the downward movement has not exceeded the rate of upward growth of the coral. If subsidence continues long, the upward growth of the coral will diminish the size of the lagoon, the place of which may come to be taken by a very small coral island. Thus the paradoxical statement is true, that the small size of a coral island may be proof of its antiquity. Recently emerged islands are necessarily destitute of vegetation, and time is required before the waste of the coral provides a soil on which plants may grow. The introduction of seeds may have taken place by their drifting from some wooded island, by their being carried in the soil lodged in hollows of driftwood, or attached to the feet of birds, or dropped undigested by them. The amount of life is small in such islands, and the variety is not great, but the distinctness of the species from those of adjacent lands is often extreme.

The barrier reefs and atolls have usually one or more openings, leading into the enclosed water. These correspond to the position of streams descending from the island during its submersion, the coral not growing at these points where water, charged with impurities, flowed over its surface. Dana finds in the irregular outline of the islands another proof of subsidence; for, the valleys having been formed by streams, and the notches with which they indent the coast being produced while the island is above the water, the existence of irregularity of outline shows that submersion has not lasted long enough to allow the sea to smooth away the inequality.

The lands on which the reefs grow may be either volcanic or, as has been said, may be a fragment of a former continent.

Volcanic islands are either entirely composed of volcanic material, or of volcanic and sedimentary materials combined. And in the latter case we may again recognise a distinction, the volcano, in one case, being the centre around which sedimentary materials have accumulated, in the other an orifice opened from beneath in the midst of pre-existent sedimentary strata.

Such islands as Saint Paul's, Amsterdam, and, above all, the temporary Graham's Island, are examples of the typical volcanic island, the genesis of which seems to be traceable in the shoaling of the Atlantic basin along a line connecting the most westerly point of Africa with the most easterly point of S. America. That actual elevation of the sea floor takes place is unquestionable; but in Graham's Island, and in the submarine Atlantic formation, we have evidence of that other method of raising a cone by the superposition of lava and ashes which have been poured out from a crater.

The north-eastern peninsula of Celebes furnishes an example of the fusion of an originally distinct volcanic island with an adjacent land mass, the elevation of both ending in the ultimate junction of their bases at and above sea level.

The volcanic islands of greater antiquity, as Madeira, Teneriffe, Sumatra, Japan, exhibit every gradation from those of which the volcanic rocks form the nucleus, to those of which they are, so to speak, only later accidents. The animal and vegetable population of these islands suggests sundry very complicated problems, which we are not yet able to solve, the distinctness of the faunas of Madeira, Porto Santo, and the Azores, not being explicable, save by the conjecture that they have been separated for very long periods of time, during which important specific variations have been brought about.

40. Submarine Gravel Banks.—The last point which remains to be noted regarding islands is the evidence of their ultimate disappearance. On the charts of the English Channel, shoals occur which are "awash," that is to say, level with the surface of the sea; others are at various depths beneath the surface, and on these accumulations of gravel are found, proving their submersion. For gravel, the coarse detritus of land, is a shore accumulation, and when it occurs in patches at some distance from land, it obviously could not have been transported, but must have been formed where it is found, and in the case of Jones' Bank, must have been formed on the shore of an island, of which that shoal is the submerged representative.

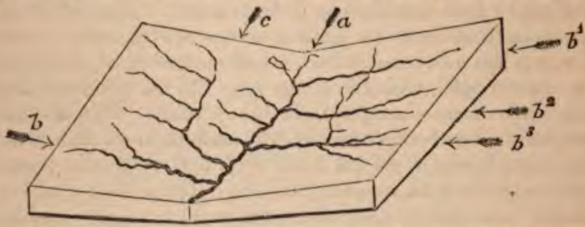
SECTION III.

Relief of the Dry Land—Its Features dependent on External Agents and on Subterranean Movements—Plane of Marine Denudations—Valley Formation—Hilly Districts of Britain—Transverse and Longitudinal Valleys—Shapes of Valleys—Sections Pointed, Truncated, and Rectangular, or Evenly Curved—Remains of Older in Newer Valleys—Axis of Elevation does not Remain in Centre of Land Mass—Hills and Mountains—Sand Dunes: Gravel Mounds; Moraines—Linear Directions of Chains: Scandinavia; Ourals; Pyrenees; Alps; Asia Minor; Asia; Africa; America—Axes of Elevation not Parallel—River Valleys in England—Western Escarpment of Mesozoic Rocks—Forms of Hills: Rounded, Serrated, Precipitous—Cliffs—Escarpments: their Origin by Denudations, not Faults, nor Marine Action—Grouping of Hills into Chains—Table-Lands.

41. Relief of the Dry Land.—Hitherto the horizontal area of the dry land has been considered. We turn now to consider the varieties of surface which it presents. The relief of its surface depends on two influences: the upward or downward movements which originate within the crust of the earth, and the denudation which sea and atmosphere unite in producing, while local modifications are the result of volcanic outbursts. What is above the surface of the sea is, however, the same in all essential characters with what is below; the land of the present time has been at former periods the floor of ocean, and the sea-bottoms of to-day will in time appear, in their turn, as dry land. We are thus enabled to take a comprehensive view of the features of the land, and to reduce the phenomena of land and submarine surface to one general law. It has been found convenient to treat of islands as distinct from the continents. In discussing the contours of the land the distinction disappears.

42. Subterranean Movements. — All rocks that are neither volcanic in their origin, nor, like coral reefs, due to the direct action of animals, are sedimentary, their primitive aspect being sometimes obscured by that change of chemical composition and texture which is known as metamorphism. The land having been accumulated under water, had its materials at first arranged in definite order. That order may have been disturbed by subterranean movements, whereby the strata have become tilted, crushed, fractured, and otherwise disarranged, and the mass may not be elevated above the sea till these changes have taken place. But if such a disturbed mass comes within the influence of the waves, denudation smooths off its asperities, and it finally emerges from the ocean with an even surface. The strata, if elevated without disturbance, likewise emerge with an even surface, and this we must take as the starting point in our investigation of the features of the land.

43. Plane of Marine Denudation. — Though even, the surface is not necessarily flat, probably never is flat, but presents a gentle slope from a central position, slightly elevated, if we suppose a mass to be raised *de novo* from beneath the sea. If the mass is nearly circular the slope will be *quaquaversal*, that is, in all directions from the centre; if it is elongated, the centre will form a ridge with opposite inclinations, and sinking at either extremity into the sea. The gentle seaward slope, "the plane of marine denudation" (Ramsay), is the result of the horizontal action of the waves on the vertically ascending land, the resultant of the two forces yielding a plane whose inclination is proportional to the speed of elevation on the one hand, and the intensity of wave action on the other. As soon as land appears, moisture descends on it; and as the mass enlarges the moisture increases, so that at last little rills are formed. The first drops of water which sought a lower level took the shortest route down the slope, that is, at right angles to its axis, and thenceforth the position of a valley was determined, which every subsequent increase in the size of the rill deepens and widens. If two such rills are immediately adjacent, the deepening of their hollows renders sharper the ridge of ground which separates them, and thus another series of slopes is produced, from which again streamlets descend by the shortest course nearly at right angles to their axes; thus secondary streamlets are formed, and as these go on deepening their channels, the ridge between them becomes lowered, and we may finally have two such secondary streamlets flowing in opposite directions, in what appears at first sight a



RIVER, receiving tributaries on both sides, flowing in the direction indicated by the arrows. The primary tributaries b, b, enter the main stream at right angles. The deepening of the tributary valleys leaves between each pair a sloping ridge which secondary streamlets descend, as in b^1, b^2. If these eat back the intervening ridge a connecting valley may result, such as that connecting b^2, b^3. Several of these may unite as at c, and form a valley parallel to the main one, from which, as it deepens, it becomes separated by a ridge.

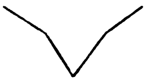
single valley, or one without a water parting. If the deepening of the secondary streamlets proceeds more rapidly than the deepening of one of the primary valleys, the secondary valley may intercept the waters of the primary, and thus we may have the principal drainage of a district effected by a channel which is, for a large part of its course, parallel to the principal river of the region. In the south of Ireland, Mr. Jukes has shown that the Bandon and Lee, which appear as the main drainers of the district, are in reality secondary streams which have intercepted the primary water courses, and at last rejoin a primary valley at right angles to enter the sea. Such, in brief terms, is the theory of the origin of valleys by river action, or, in more general terms, by atmospheric denudation. It appears, then, that the original contour of the country is that of a flat surface or plain, and that the hills, whether isolated or in continuous chains, are in reality portions of the original plain, which have been left outstanding between grooves excavated by atmospheric denudation. The hills of a region are, in other words, very rarely due to elevation, but are for the most part the result of denudation. In Wales, Professor Ramsay showed that the plane of marine denudation is still recognizable, since a line drawn from the summit of Snowdon to the sea would be above every peak intermediate between the two ends of the line. In Scotland, both in the north and south, the same observation holds good, the hilly districts having central heights which are the axes of the original elevations. Thus we have Great Britain divided into six hilly districts: Wales, Cumberland, the southern Highlands, the region between the Grampians and the Caledonian Canal, and the region lying to the north-west of the Canal; and each of these has the same character, consisting, namely, of a central principal axis, with a series of peaks and ridges gradually descending therefrom. In these localities we have on a small scale the same arrangement which is met with on a large scale in other continents, namely, the Cumberland hills represent a nearly circular mass of heights, while the Scottish hill masses are all arranged in chains, whose direction coincides with that of the longitudinal axes of elevation.

44 Transverse and Longitudinal Valleys.—The valleys descending from a doubly sloping ridge are transverse to its axis, and to any valleys which may be formed parallel to that axis. Madagascar, Sardinia, and some other islands, consisting of a simple ridge, exhibit only transverse valleys. The map of Scotland, perhaps, best illustrates the transverse and longitudinal systems. The mass of high ground, whose middle line runs from the Ross of Mull to midway between Cape Wrath and the Pentland Frith, is grooved by streams which run generally to W.N.W. and E.S.E. The Sound of Mull is apparently formed by two such valleys, which have lowered the intervening water parting, till practically a single valley has been formed. The longitudinal valleys are formed by the deepening of tributaries at a more rapid rate than the main stream; thus the tributaries are intercepted and carried to N.E. and S.W., while the continuance of the lowering process ultimately lays these two valleys into one, and a longitudinal valley is formed, which, if the land is depressed, becomes an arm of the sea, isolating a larger or smaller tract of country. If such submersion takes place slowly, the abrading action of the waves planes down the floor of the valley, so that on re-émergence we should expect to find a smooth surface, from which all trace of the original water parting has disappeared. The influence of the sea on the form of such a valley is exerted in widening it and in smoothing it down, so long as its floor remains within the action of its surface waters: but there is a limit to its operation; for, though there is evidence that the great valley of the Forth and Clyde has been beneath the sea, a distinct water parting has survived the submersion, and the streams flow in opposite directions.

45. **Shapes of Valleys.**—The water parting in the imagined case of a newly elevated ridge, coincides with the summit of the ridge; but, as the ridge is lowered at the points corresponding to the head waters of streams descending in opposite directions, gaps will be formed, and, as the lowering process goes on, till at last the valleys become continuous, the common groove will become a pass. If a larger body of water, or softer strata, enable the stream on one side to eat down the gap more rapidly than it is being worn away on the other, the water parting will become sinuous, and the sources of the streams would appear on the map to interlace.

In temperate regions, the shape of such valleys as have been described, is that of a triangle V, the apex of which may in the larger valleys become truncated __/, the flattened area representing the alluvial flats formed by the flood-borne detritus. But the action of the stream at the bottom of the groove goes on along with the disintegrative action of the atmosphere on the higher part of the walls, a slope being thus maintained on either side. In rainless regions, such as that of the Zambesi, in Africa, or the Colorado district of western N. America, the stream wears down its channel vertically, and the shape of the gorge is more nearly rectangular |__|, the channel of the Zambesi below the falls as described by Livingstone, and the cañons of the Colorado district, sometimes 3000 feet deep, being stupendous examples of the power of unaided streams. Such valleys, moreover, have their lines very irregularly disposed, manifesting little subordination to the axis of greatest elevation in the district. In glaciated districts on the other hand, as in the British Islands, the passage of glaciers down the valleys has obliterated the angles, and given the regular curve ⌣ characteristic of ice-worn channels. The difference of form of valleys thus gives a guide to their age, the convergent slopes being peculiar to those grooves which have been excavated since the ice period, whether on the sides of a hill, or in the glacial detritus with which a wide valley has been partially filled up.

46. Remains of Old Valleys.—A river valley for the most part has the stream flowing at its lowest level; but in temperate regions, a river bed is sometimes above the level of the lowest point, is in fact scooped out on the side of the valley, and parallel to its axis. These exceptional cases are confined to ice-worn districts, and suggest that the stream, or the glacier, has worn down a new groove, leaving the original stream channel as an index of the amount of denudation which has taken place since it formed the sole drain of the district. In the same districts we often observe that the walls of the valley slope in two distinct planes on either side; the upper, more gentle inclination representing the original form, through the floor of which the latter more acute angled valley has been worn.



The abrupt change in the walls of a valley, from gentle slopes to almost vertical gorges, is a phenomenon chiefly associated with glaciation, the gorges being for the most part rock-worn channels, which the stream has cut for itself since the glacial period, having been unable to wear through the detritus with which its old channel had been choked up.

The walls of fiords or submerged valleys, which indent the west coast of Scotland, Norway, Ireland, and S. America, are either continuous or interrupted; for if the submersion only bring down the ridges nearly to the sea level, the *cols* become channels, isolating larger or smaller peaks.

47. Axis of Elevation.—In the imaginary case of newly elevated land, we have assumed that the axis of elevation coincided with the middle line of the mass. But this is not the case in land masses of any antiquity. In them there is a gradual rise from the coast towards the greatest heights, and these, as has been already mentioned, are usually found nearer to one or other coast line. Thus, in S. America there is a gradual ascent on the east side, an abrupt descent to the western shore. The long slope may be either uniform, or, as is more frequently the case, interrupted by terraces. It is usually stated that a long slope on one side has a steeper counter slope on the other side; but, from what has been said regarding river valleys, it is clear that this general statement only describes the large valleys whose ridges separate them from more recently excavated grooves. The gradation, therefore, in point of age among these parallel or intersecting valleys, explains the variety of the inclinations, and suggests that the lesson often taught to military engineers, the slope on one side is nearly the slope of the other side, is a rule open to exception to begin with, and still more liable to be inaccurate when the action of ice in one, but not in the adjacent valleys, is remembered as a not unfrequent event.

48. Mountains and Hills.—The low undulations of a country which has been abandoned by the sea, and on which atmospheric agents have begun to work, stand to the grand features of such mountain masses as the Himalayas in the same relation as the islet to the continent. The height of the undulating surface above the sea is in exact proportion to the depth of the furrows, so that, in general terms, elevation and denudation go together in assisting to determine the relative age of the high grounds. The advocates of atmospheric waste as the agent to which we chiefly owe the features of the dry land, do not exclude the sea from all share in determining the position of future valleys. No surface, probably, is ever left absolutely smooth; and the mud bank of an estuary shows, as the tide ebbs, the kind of inequality to be expected on a large scale in emerging continental land. [illegible] *ght hollow* helps the atmosphere to commence, but without such a help, the atmospheric moisture would of necessity excavate grooves for itself.

The outstanding features are hills, mountains, and table-lands, plateaux or terraces, terms to which certain tolerably precise meanings are attached popularly, but which it is very difficult to define, so as to establish a real difference between them as regards their origin. The cliffs, escarpments, and slopes, by which these features merge into each other, are more easily dealt with.

Between a hill and a mountain the only difference is a convention of language, by which the latter term is vaguely limited to heights of between 2000 and 3000 feet and upwards; the employment of one or other term does not therefore, from a geological point of view, involve error.

Hills are detached or connected by their bases into groups of various forms, the linear arrangement constituting a range; the junction of several ranges forms a group with more or less radial arrangement, while system refers to the ranges or groups which, in form and position, belong to the same period, to the same region, or what comes to the same thing, are due to the same processes of elevation or denudation.

Inequalities of the surface are caused by denudation, by the outpouring of volcanic or other materials from the interior of the earth, and by the shifting of loose materials on the surface of the earth.

In Scotland, isolated cones of gravel are frequent towards the coast lines; and though many of these are obviously denuded fragments of sand and gravel plateaux, others have certainly been left as we now see them by the sea, which, at the close of the glacial period, covered the low grounds. The heaping together of the gravel by cross currents of water, brings submarine and subaërial deposits very close together.

49. Sand Dunes, etc.—Sand dunes form ranges, the relations of which are often very interesting. The wind blowing from the sea carries from the water edge a roll of loose sand, and drives it onward till it is arrested by the slope of the shore, or by some other obstacle; the piling then goes on, the particles travelling up one side and down the other, so that the masses travel forward by stages, the breadth of which is half the breadth of the base of the sand ridge

These mounds can only be formed where a wind blows on the shore steadily, or, when it is not blowing, no other wind passes over the surface with equal strength and frequency. Hence the parallel ridges of the dunes inland, till cultivation, or a wood, or a river, arrests them. In this country these ridges are trifling for the most part, the greatest development of them being on the north coast of Cornwall. But in Africa, for example, the movement of the desert sand over the Egyptian plains, where gaps occur in the high grounds separating the two regions, is on a grand scale of destructiveness, and in the Thurr or sand desert, which lies north of the Runn of Cutch and east of the Indus, the ridges attain to 400 feet in height, their summits being thus 500 feet above sea level. It is right to mention, however, that Sir H. Bartle Frere doubts this explanation of the origin of these ridges, and suggests a series of parallel fractures and subsidences as one of the many volcanic phenomena of the district.

The mounds of glacier detritus, the terminal moraines of extinct as well as existing glaciers, form piles of no inconsiderable importance in some valleys, those of the Val d'Aosta attaining a height of 1600 feet above the plain. They are mentioned here simply to enumerate in conjunction all the surface features.

50. Bearings of Ranges.—The directions of the linear ranges and the grouped systems of hills varies in different regions, as the following table, an abstract of that given by Jukes,[*] shows. The orientations are reduced to Bingerloch, and they have not been corrected to any British locality, as it is intended to show the relations of the systems to each other, not to any particular point:—

N. 1° 11′ W.	Corsica, Sardinia. Red Sea, Hungary, Syria. Upper part of Loire and Allier, Rhone.
L. MIOCENE.	
N. 2° 30′ E.	Malvern Hills. I. of Gothland. N. of Russia.
PERMIAN.	
N. 15° 46′ W.	Greece. Italy. Sicily.
N. 21° 4′ E.	Vosges. Ireland. Scotland. Scandinavia.
N. 31° 15′ E.	Longmynd. Saxony. Sweden, Finland.

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[*] *Manual of Geology*. Second Edition.

CAMBRO-SILURIAN.	
E. 4° 32′ N.	Isle of Wight. Satra (Carpathians). E. Alps. Jura.
EOCENE.	
E. 2° 0′ N.	From Elbe to St. Bride's Bay. Brittany. S. Ireland. Thuringia. S. Russia.
E. 15° 6′ N.	S.E. England. N. France. Spain. N. Africa. Atlas. Caucasus.
E. 37° 55′ N.	Oolitic Escarpment, England. Saxony. Monte Pilato.
W. 23° 3′ N.	Pyrenees. Italy. Sicily. Greece. Carpathians. Weald of Kent.

An attentive comparison of this table with the map will show, more especially if the student refers to detailed maps of each locality, that it is easy to construct parallels if we disregard the dates and amounts of denudation in favour of assumed elevating movements.

51. Mountain Systems.—The Scandinavian peninsula is traversed by a ridge of continuous heights, of which Sulitelma is 5956 feet in height, Skagesloestinden is above 8000 feet in height.

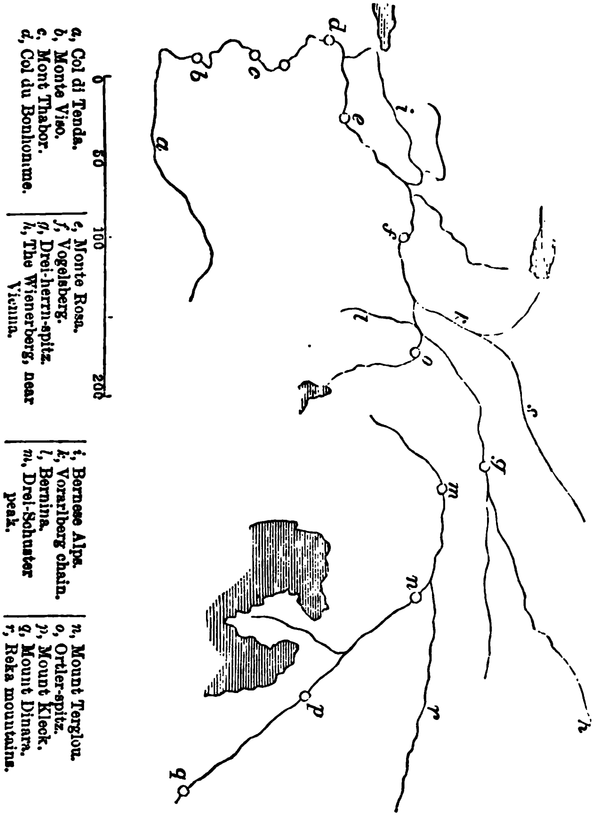
The axis of this chain is north-east and south-west. The northern portion of the chain is higher than the southern, and the snow line at the seaward side descends to 3200 feet above the sea level. The axis would, if prolonged, intersect the protracted line of the Oural mountains, while, southwards, the British Islands may be regarded as a member of the chain which bordered the European continent to the north-west and west, as the geological structure in both countries is the same.

The Ourals extend over more than twenty degrees of latitude, dying out southwards in the plateau of Sakmara, while the higher peaks are situated in the northern portion, and the average height is about 2500 feet. This, the eastern limit of the European area, has its longer slope to the westward, the steeper declivity fronting the lower plains of Asia.

From the sea at Cape Finisterre, to the shores of the Black Sea, a nearly continuous line of mountains traverses Europe, and, through the Caucasus, the line is prolonged through Asia, running out in Burmah. The Pyreneean section of this long line has been elevated since the chalk period, and now constitutes a natural barrier between France and Spain, having an average height of 7000 feet, without any low passes intersecting it. The highest peaks are Maladetta, 11,168 feet, Penaranda, 10,663 feet, Pic de Nethou, 11,426 feet, Mont Perdu, 11,994 feet. The slopes are the reverse of what is usual along the great east and west chain, for the declivity into Spain is shorter and more gradual than that into France. In fact, the Pyrenees are the northern rampart of an elevated plateau from which several ridges approximately, east and west, project; of these, the most northerly are the Cantabrian Mountains, which are almost a continuation of the Pyrenees, and the most southerly, the Sierra Nevada, parts of which approach 12,000 feet. The snow line of the Pyrenees averages 8000 feet; in the Sierra Nevada it is at 11,000 feet.

The nucleus of the Alpine system lies between the sources of the Rhine, Rhone, Ticino, Inn, and Adda; it gives off to the S.W. the Italian Alps, of which Corsica and Sardinia are appendages; to the N.W., the Gallic Alps; to the S.E. the Apennines, which are separated from the central mass by the valley of the Po, almost as completely as South India from the Himalayas by the Ganges; on the N.E., the German Alps pass towards the Sarmatian plain, of which the southern boundary is formed by the Carpathians; while the Hellenic Alps are the S.E. prolongations, reaching through the Balkan to the Black Sea, and forming, by its southern spurs, the deeply intersected south-eastern corner of Europe. The heights in this extensive system are Etna, the most southerly point 10,874; Mount Athros, 9628; the highest of the north-easterly branch does not exceed 9000 feet; the Glockner is 12,956 feet; Mount Blanc, 15,784 feet; Mount Pelvoux, 13,468 feet, and the Gallic portion has an average of 5000 feet. A large part of this group is the seat of perpetual snow, and of large glaciers, the snow line averaging 8500 feet, being lower on the south than on the north slopes.

The Caucasus, the Taurus, and Antitaurus, form the connecting link between the Alpine and the Himalayan nuclei. The Caucasus rises above the snow line at many points, its *maximum*, Elburz, being 17,112 feet. The Armenian or eastern portion of the Taurus and Antitaurus culminates in Mount Ararat, 17,200 feet, and Demavend, 21,000 feet, is a peak of the range which merges in the Hindu Kush,



while the Taurus is prolonged eastwards in a sinuous, but not very high range to terminate at the same point. From this nucleus, the Kuen Lun range passes eastwards as the proper continuation of the Europeo-Asiatic line, while the Himalayas bend to the S.E., and maintain a uniform aspect facing the Indian Ocean. The Indus and Brahmapootra rise on the north side of the range, and, flowing in opposite directions, breach the rampart at its western and eastern ends, so as, with the Indo-Gangetic valley, to insulate the principal part of the range. The highest peak, Everest, is 29,002 feet, and the mean elevation is between 15,000 and 16,000 feet. To the north-east, the Himalayan line is continued through a region the details of which are unknown, save that it consists of complicated mountain chains, by which the transverse system of Central Asia is connectec with the great Altai system, which runs from the source o the Irtysh to Behring's Straits; parallel ranges lie to th north and south of this main line, and separate differen plateaux from each other, while the circle of mountains just outlined encloses the great table-land of Asia, the drainage of which is, to a large extent, inwards. The ridges north of the Himalayas rise to a great height above the sea level, the central portion attaining to 10,000 feet, while either extremity of the range sinks to an average of 5000 feet, but these chains are all portions of the original plateau of Asia; they are fragments of plains left outstanding by denudation. Modern as is, geologically speaking, the elevation of the Himalayas, they present a grand illustration of atmospheric waste. Rising from the plains of India by successive ridges, the troughs separating these parallel ramparts are longitudinal valleys, while transverse valleys intersect the slopes with remarkable regularity, and the southerly spurs which run towards Cambodia and the Malayan Peninsula are channelled out by the streams which flow between them. The snow line of the Himalayas is about 15,500 feet on the south, 19,600 feet on the north slope; glacier action, therefore, is intense in a region large part of which is a constant snow field, whose valleys, beyond the limit of the glaciers, are occupied by perennial streams, and are flooded at the same time that the monsoon brings rain over the plains of Bengal. When to this is added the fact that the westerly or south-westerly upper current of the atmosphere is, so to speak, tapped by the mountain range which forms a natural boundary of the basin of the Indian Ocean, it is apparent that on this range are concentrated all the agents of atmospheric waste, and that thus, in a comparatively short time, and among rocks of considerable relative hardness, denudation has produced results comparable with those which, in more northern latitudes, required long ages for their elaboration.

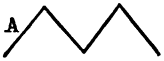
Our knowledge of the interior of Africa is not such as to enable us to speak with certainty of its mountain ranges. The grounds on which an east and west chain is believed to traverse Central Africa are, as Laughton sums them up, (1), the known high lands of Abyssinia; (2), the equatorial mountains on the west coast, the Cameroons, and others seen stretching, peak after peak, into the interior; (3), the lofty mountains seen by Denham to the south of Bornu; (4), the intimate and singular relationship between the mountain flora of Abyssinia, of the Cameroons, and of Fernando Po. The Atlas, to the north of the Sahara, is parallel with the S.E. chains of Europe, and its parallel ranges gradually ascend from Tripoli westwards, from 2000 to 13,000 feet, the summits being thus within the snow line. The Straits of Gibraltar are excavated through a northern spur which formerly closed the Mediterranean. The Abyssinian mountains are, in reality, a table-land of an average level of 8000 feet, from which ridges project to more than 15,000 feet above the sea, while the intervening valleys are of great depth, the gorge of Jitta being 3500 feet deep. The depressed plateau of S. Africa rises southwards, and, in the Cape district, the plateau is worn into mountain ranges which are parallel to each other, and which present gradations of height up to 6000 feet. The kloofs or ravines which cut into the successive tables, or karroos, are results of denudation of a kind curiously characteristic of all flat elevated lands. It is wrong to speak of the karroos as terraces; their surface is interrupted by outstanding low heights, denuded hillocks, which mark the rate of denudation. The kloofs are transverse water channels, which will gradually encroach on the karroo ground till only sharp ridges separate the ravines. A glance at the map of Livingstone's explorations shows that this kind of denudation extends into the lake region.

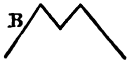
The two halves of the New World agree in having, in common, a mountain range the features of which are generally similar. The Rocky Mountains in N. America, the Andes in S. America, are connected across the central district by an essentially volcanic region, bordering the Mexican Gulf. The heights of the principal peaks are variously stated, but the following are probably correct enough to give the general relations of the summits. The Patagonian section is of moderate height, not exceeding 8000 feet, the height of the volcano Minchinmadiva. The Chilian division forms a single range as far north as 30° lat., rising, at 41° lat., to 16,000 feet in the volcanic Villa Rica; Maipo is 17,660 feet; San Jose, 18,150; Tupungatu is variously estimated at 22,000 and 15,000, probably in consequence of confusion of names between it and Aconcagua, which is 22,296 or 23,910 feet. The Bolivian section includes the double chain of the Andes, and the commencement of the spurs which once connected the main chain with the lower parallel ridge of the Cordillera Geral, but are now intersected by the tributaries of the Madeira river. In this region the salinas, or salt deposits of the table-lands, are found. The sinuous ridge which passes eastwards in 25° lat. S. is the commencement of the eastern great chain; the peaks are somewhat irregularly placed, being volcanic to a large extent; among them are Colorados, 12,406 feet; Cerro di Potosi, 16,000; Chorolque, 17,000; Cochabamba, 17,000. The range which forms the proper eastern wall of the Titicaca valley commences southwards with an average of 15,000 feet, and rises to Illimani, 21,252 (24,200 of some writers), Sorata, 21,286, and sinks north-westwards to Vilcausta, 17,500 feet, whence the eastern range gradually disappears, being dismembered by the streams which form the head waters of the Amazon. The western ridge may be regarded as itself a double mass, of which the highest peaks are Gualateiri, 22,000; Sahami, 19,450; Parinacota, 23,000; Arequipa, 20,300; Chuquibamba, 22,000. From the latitude of Cuzco northwards, the chain continues of an average height, no greatly outstanding peaks occurring in this portion, which corresponds to the area of meeting of the cold southern and warm northern oceanic currents, heavy fogs *being* the obvious sign of their mixture. Northwards rise

Chimborazo, 21,450 feet; Cotopaxi, 18,880; Antisana, 19,150; Cayambe, 20,140; Tohnia, 18,120.*

52. Axes of Elevation.—The details of the areas, of which the principal features have been summarily indicated, may be learned from special treatises. But from the sketch that has been given it will be apparent that, to a very large extent at least, atmospheric denudation has fashioned the surface of all countries. The somewhat cumbrous generalisation has been put forward that the continents are older than the mountains; but this is only true for the mountains which have been raised into prominence by subterranean movements, since—if the theory which has been developed holds true—the mountains are for the most part fragments of older table-lands. The elevation of any region to such an extent as to determine the direction of its waters, may take place at any period subsequent to the appearance of the region as dry land; that elevation which gives to one portion the relative height held by convention to constitute a mountain, may either be continuous or effected by many successive movements, at longer or shorter intervals, and of variable intensity.

The axis of a mountain chain which may have been formed by elevation corresponds theoretically, as it certainly does primarily, to the summit of the anticlinal ridge into which its strata are bent. A represents two anticlines with intervening syncline; but, after long ages of denudation, the relative positions of these two may be reversed, and the bottom of the synclinal curve may come to form the top of the hill, the greater part of the anticlines on either side being worn away as in B. Ben Lawers represents such a condition, the strata dipping on each side towards the centre of the mountain, the top of the hill being the bottom of the geological trough. But a more striking illustration is offered by the Scuir of Eigg, as described and figured by A. Geikie.





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* Very few of the heights here given are accepted by all writers, the differences being due partly to defective knowledge, partly to inaccurate *repetitions*.

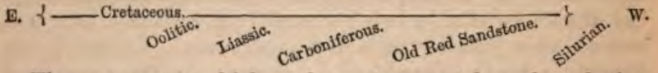
The Scuir is a mass of volcanic rock with vertical sides, which stands on the summit of a hill; but it is in reality a lava flow which occupied the bed of a stream, whose gravel is still found in place below the lava. The banks of the stream have been worn away; the bed of the stream now terminates a conical hill, and the lava which once filled up the bottom of the valley now forms the apex of the hill.

M. Eliè de Beaumont believed that by comparing the directions of mountain axes, and determining their parallelism, the dates of their elevation might be approximately determined. But subsequent fuller information led him, in 1853, to modify his views by the admission of several dates of elevation in the Pyrenees, and this admission for a single chain is practically the adoption of the hypothesis of slow and successive movements. Sir Charles Lyell urges, in favour of the slowness, that even in such a case as the Pyrenees, where one of the movements took place between the cretaceous and tertiary deposits of the region, the cretaceous beds were not necessarily the latest, nor the tertiary the earliest of their respective epochs, and that therefore a very long interval may have given time enough for a considerable amount of vertical movement.

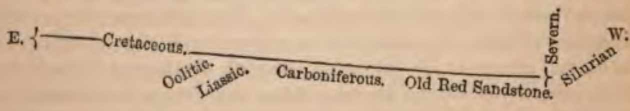
It is further to be remembered, that satisfactory approximations to the date of movements depend upon accurate identification of the deposits, and as these are becoming gradually more precise, our chronological arrangements are liable to important modification. The re-examination of the Longmynd gave proof that the strata of which it is composed are silurian, and that therefore the elevation was post-silurian, and the correction of one opinion founded on necessarily imperfect knowledge suggests caution in the adoption of a view which implies that there is, in the chemical phenomena underground, a regularity and periodicity which cannot be affirmed for the chemical or mechanical phenomena by which the surface is affected. Thus, to take the succession of volcanic outbursts in Britain: the silurian strata are traversed by dykes, or injected masses of later date than the beds which they break up; but the contemporaneous lava sheets, evidences of volcanic activity at the surface of the earth during their deposit, are chiefly found in

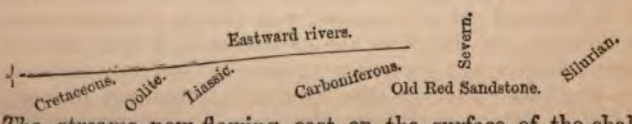
Wales, traps and ash entering largely into the structure of Snowdon. The old red sandstone period witnessed many active volcanoes north of the Tweed; in the carboniferous period, volcanoes emitted lava and ashes at almost every stage, but the locality was not always the same, and Prof. A. Geikie has very clearly set forth the alternate quiescence and activity of the various districts. During permian times the outflows are abundant, and volcanic vents referred to this period are found at some distance even from the nearest permian strata. The mesozoic strata were deposited in Britain during a period of quiescence, and the tertiaries of England are undisturbed. In the middle of Scotland, which had been the chief seat of carboniferous volcanoes, there is no later development on any considerable scale; but in the west, from Antrim to the Faroe Islands, the miocene lavas were not merely poured out in enormous quantity, but have since undergone an astonishing amount of denudation—Mull and Eigg, for example, being isolated fragments of a trappean plateau, once probably well nigh continuous. To this period belong the latest volcanoes of Auvergne. In the succeeding times, the site of volcanic activity has been transferred to the Mediterranean area, and to a zone which includes Hecla and Jan Meyen. So far, then, as it is possible to estimate with safety the relative length of different geological epochs, the intervals between these various developments of volcanic activity are unequal, and the phenomena are, for each period, limited in the area they occupy. If, therefore, there is reason to believe that elevatory movements and volcanic outbursts have, if not identical, at least closely similar causes; and if, as also seems probable, the subterranean cavities in which volcanic products are generated are connected with each other, the irregular recurrence of the phenomena is not such as to justify any general statement regarding their results. Bearing in mind that this forms a difficulty in the way of explaining the irregular occurrence of eruptions, as much as in the way of determining the periods of subterranean movements, the belief in the separation from each other of these subterranean reservoirs would still further complicate the question. For on that hypothesis we should be compelled to seek *on the surface* the cause of this development of elevatory movements in parallel directions at distant localities. And reference to the map of the world given by Darwin (Coral Reefs) shows that at this present time movements in opposite directions take place in adjacent districts to the south of the equator, while in the north also antagonism of the same kind occurs—Greenland descending while Disko is being elevated: the north of Scandinavia is slowly rising while the extreme south is as surely sinking.

53. River Valleys in England.—Professor Ramsay, in his investigation of the history of rivers, has given good reason in support of the following as the course of events in S. England. The mesozoic period was brought to a close by a general depression, during which the cretaceous rocks covered over unconformably the oolitic and all older strata, abutting against the Welsh silurians. (The three following sections are supposed to be seen by a spectator looking south).



The movements which we know to have taken place during the early tertiary times in Central Europe, were associated with a tilting of the French and English areas, so that the cretaceous beds dipped to the N.W., and thus a groove was formed, at the bottom of which a stream ran, with the silurians for its westerly bank. The Severn, thus commenced, continued thereafter to flow in the same direction, but the atmosphere cut back the chalk in the escarpment form now seen, and afterwards the east of England was again tilted, so that its incline sloped in the opposite direction.





The streams now flowing east on the surface of the chalk maintained their direction while the chalk escarpment was gradually eaten further back eastward, and thus they seem to cut through a high ground, whereas in reality the escarpment has receded past them.

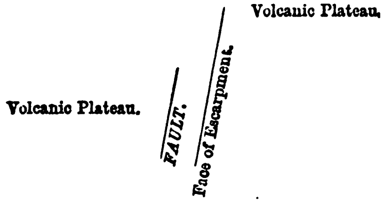
54. Forms of Mountains.—The forms of mountains, their aspects, varied as they may appear, have very close relations to their structure and the influences to which they have been subjected. The flat summits of the fragments of table-lands, as Table Mountain, and the hills of Saxon Switzerland, and of trappean plateaux, as in Auvergne, are similar, because both consist of rocks laid down in horizontal strata which retain their relative position. The smoothly rounded summits of the hills in S. Scotland, and the lower heights in N. Scotland, Wales, Ireland, some parts of Central Europe, and America, are due to the action of ice passing over ground which once formed a plane of marine denudation, and which still retains the primitive relation of its parts, notwithstanding the denudation which its surface has undergone. The wide, even curves of the gaps which intervene between the heights, tell, in Brazil as in Europe, of the passage of ice through the strait, leaving a channel of symmetrical form.

The serrated ridges which give to many mountain masses their peculiar character, for which restlessness is the best expression, are due to the similarity of texture of the ranges, as much as to the length of time during which they have been exposed to denudation. The highly altered slates and schists of metamorphic districts weather unequally along the strike of the strata, and thus give an irregularly rugged outline, which, when large masses of unequal hardness alternate, becomes exaggerated into the pointed peaks constituting the aiguilles of Alpine scenery. In a country the hills of which have in general the rounded smooth outlines of ice-worn summits, many of the lower heights may come to present, as in the Scottish Highlands, serrated summits; while the hills of S. Scotland, though exposed to atmospheric waste for an equal length of time, since the glacial epoch, very rarely lose their smoothness, their softer consistence permitting them to weather more evenly. The outlines of trappean plateaux in the last *stage of disintegration* are similarly ragged, but the peaks are more symmetrical pyramids, their texture being uniform on all sides.

55. Cliffs and Escarpments.—Some hills, or ranges of higher ground, terminate not by slopes, but by abrupt precipitous faces. These are spoken of commonly as cliffs, the same term being applied to them as to the similar faces of rock which border a coast line. It is, however, desirable to employ a different term for many of these inland features which are not due to marine denudation. Cliff and escarpment are the two terms which field geologists have adopted, the cliff being the result of marine action, the escarpment of atmospheric waste. The base line of the sea-worn cliff is always horizontal, that of the escarpment may or may not be so. If both are composed of strata which undulate, the sea which can work only along a horizontal plane, disregards the undulations; the atmosphere, which works most rapidly along the lines of least resistance, makes a hard stratum the base of the steep face, and if the upper surface of that hard stratum undulates, the base line of the steep face undulates also. The escarpments of the chalk and oolites in England illustrate the departure from the horizontal of the base line, and the undulations determined by a harder bed; sections, moreover, drawn in the chalk district by help of the Ordinance Survey maps, prove the base of an escarpment to be higher at one than its summit at another point, an impossible relation in a sea-worn cliff, unless, subsequent to its formation, violent disturbances can be demonstrated.

Without denying the possibility of vertical precipices of great height occurring, their number must be very small. A river or the sea undercuts its shores, and thus would maintain, if no other action took place, constantly vertical faces; but the sides of a valley, and the cliffs along the coast, all slope either evenly, or by ledges which are determined by the relative hardness of the strata. Perpendicular faces very rarely have a greater height than the thickness of the stratum in which they occur, and this form is very persistent; it is due to the jointing of the rock, or that (Art. 26) which leaves a vertical face after each successive landslip.

Very few cliffs or escarpments are due to faults. The steep face only rarely represents the mass of strata along the line of fracture, towering above the portion which has sunk down to a lower level. The fissure or line of parting between the two masses of rock seldom if ever gapes at the surface, and if the movement of the two masses past each other left at the surface an inequality, atmospheric and marine denudation would in their turn strive to smooth it down, so that unless the feature were of recent development, it would not be recognisable. In the few cases in which the escarpment owes its origin to a fault, its face is parallel in direction to that of the fault, but it has receded to a distance proportioned to the time during which atmospheric denudation has been at work. Thus—



In this diagram, where "volcanic plateau" on the left side represents the general level of the country formed by an approximately horizontal layer of trap rocks, which have sunk down from the higher level of "volcanic plateau" on the right, the face of this escarpment has receded from the line of the fault in the same way that the escarpment of the chalk has receded from the margin of the Severn valley to its present position.

56. Plateaux.—Bearing in mind that the plane of marine denudation is the starting point for all modifications of the surface of dry land, and further, that the extent to which the interior of continents is raised above the level of the sea varies in different regions, it is a necessary consequence that indications of the primitive plain should be met with at very different heights. Geographers have endeavoured to establish a distinction between mountains and hills, and have desired to modify the meanings of the popular terms, so that conventionally a mountain shall mean a more connected series of higher ground, such higher ground having the form of cones or ridges, with more or less rapid slopes, while hills shall indicate more isolated groups of smaller relative height, and mostly consisting of detached conical forms. Obviously this distinction, though convenient, is unscientific, since there is not, in the case of the features of the dry land, the same natural separation which furnishes the distinction between continents and islands. The writers referred to lose sight of the gradual transition effected by denudation processes from the primitive plateau, through hills and valleys, to the plain to which denudation tends to reduce all prominent features. As might be expected, parallel vagueness attaches to the classification of plateaux which are grouped according to their heights; commencing with those of the first class, which are more than 4000 feet above the level of the sea, we have in the profile section of Asia (*Student's Physical Atlas*, Plate VIII., fig. 2), the Thibetan Plateau of about 15,000 feet; further to the north the Pamir Steppe of about 14,000 feet, and from these great elevations a series of low terraces leads down to the Arctic Ocean, the slope of the Siberian surface being gradual. To the south of the Himalayan Mountains the descent is more abrupt. The plains of the Ganges have an average elevation of 250 feet, forming low grounds which circle round the northern extremity of the Deccan. The Mountains of Asia Minor, again, project from a plateau of about 5000 feet in elevation. The great sandy desert of Gobi is somewhat lower, while the Aralo-Caspian depression is in the midst of a plateau of about 2000 feet. In Europe (fig. 1) the Caucasian Isthmus, the Steppes which border the Black Sea, and the plains of the Danube form a great tract of low ground, which is continuous with the Aralo-Caspian tract. But Europe presents less extensive continuous plains than we find in Asia, the hill surfaces being more extensive relatively to the horizontal area. Minor plateaux are recognizable in Hungary, in North Germany, in France, in Spain, and in the British Islands. Ireland perhaps presents the largest continuous expanse of low ground. Of Africa the Sahara is the best known plateau; to the south the central area is believed to be a table-land, inclining on all sides towards the middle, constituting thus a shallow trough. In the extreme south, Table Mountain furnishes an illustration of the construction of a plateau which may be afterwards compared to the great desert of Western North America. The tablelands which occur between the eastern and western peaks of the Andes and the Rocky Mountains, the prairies in the midst of which the Mississippi flows, and the great similar tracts bordering the Amazon and the River Plate repeat again the general features of other regions. But to make this enumeration of plateaux complete, it is necessary to mention the submarine plains, of which one of the best known is that surrounding the British Islands, and indicating the western extent of Europe at no very distant date. Other plains or terraces occur at various points of the ocean floor, as determined by soundings; and if our information regarding them were complete, we should be enabled to tabulate a graduated series of different levels from the lowest point of the ocean to the summit of the Himalayas. Many of the erroneous ideas which prevail regarding these plateaux arise from the fact that sections are not commonly drawn on a "true scale," that is, one on which the horizontal and the vertical measurements are on the same scale. If such a section were drawn from the Himalayas across the Pacific to the Rocky Mountains, it would appear that the slope from the highest to the lowest points is a very gradual one, and that our division of the slope into plateaux is somewhat arbitrary.

57. **Plains.**—Plains fall into three natural groups, plains of deposit, plains of denudation, and plains of volcanic origin.

58. **Plains of Deposit** are illustrated by the deltas of great rivers, and the alluvial flats which form the coast line in many places. The deltas of great rivers are the deposits which have gradually filled up estuaries running into the mainland; their presence, therefore, is proof of a very considerable antiquity of the river valley. The mode of formation of such plains is very simple. A river carrying down from the higher grounds loose materials, and spreading these over the bottom of its channel, gradually elevates its channel so that the banks at last overtop the level of the surrounding country, as in the case of the Po and other streams. Every

overflow leaves upon the adjacent country a thin layer of silt, and thus gradually a plain is built up, the stratification of which is typical in its regularity. Even where, as in the rivers of our own country, the level of the stream is not above that of the surrounding country, the alluvial plains are still built up by a process which is essentially the same; repeated floods, raising the stream surface to the level of or above its banks, spread over the adjacent ground, and leave behind a deposit of water-worn detritus. One of the most ancient of such plains, which we may call typical or normal, is Table Mountain, the strata of which are horizontal, the mountain being in fact the survivor of an enormous table-land, the rest of which has been removed by denudation.

59. **Planes of Denudation** are the result of marine action, aided in many cases from time to time by other agents of waste. The central plain of Ireland, the Sahara, the Cheshire plains, probably large part of Aralo-Caspian plains, are illustrations of this class. We have evidence that these now level surfaces were formerly covered by thick masses of strata, which have been entirely removed, and their approximately level surface is to be regarded as a sign that, while subjected to the denuding agent, they remained stationary for considerable periods of time. When it is borne in mind that whether a plain is due to deposit or to denudation, it cannot be long exposed to the influence of the atmosphere without suffering denudation, it is evident that we have here again a very ill-defined line of distinction between these and the planes of marine denudation. If plains are elevated to considerable heights above the sea level, their waste would carve them out into deep valleys, separating hills of various forms, and thus the difference of material becomes unimportant in comparison with the identity of the processes to which the materials are submitted.

60. **Plateaux of Volcanic Origin** are small in extent, and few in number as compared with those already described. Every volcanic region furnishes examples of sheets of volcanic material evenly spread out, and giving to the landscape a characteristic aspect. In Central France, in Catalonia, in North America, we have volcanic plateaux which still retain upon their surfaces the irregularities of the scoriaceous lava.

In Britain we find, in many districts, fragments of such ancient plateaux; but they are either still covered by sedimentary strata accumulated upon them since their formation, or where these latter deposits have been removed, they may perhaps be more accurately regarded as plateaux of denudation.

The importance of these plains from an economic point of view, or because of their influence on civilization, is very great. Sandy deserts are even more serious barriers to progress than the intervention of deep and broad seas; and, even within the very limited area of Belgium, we find in the well-known colony of Gheel, a small population surrounded by the Campine, shut off from the other parts of the kingdom, and remaining in a state of primitive simplicity which it is difficult to parallel in Western Europe. The Landes of Gascogne illustrate the influence of a plain, the structure of whose soil renders it unfavourable to the health of the district; the sand of the Landes rests upon a hard cake formed of organic debris which has matted together the particles of the soil, and renders the surface liable to be converted by floods into a stagnant marsh. The removal of endemic disease from the district has been largely a result of the draining of this area, whereby a great addition has been made to the agricultural surface of France. The slow formation of a plain of deposit in the valley of the Ganges, and, indeed, along various points of the Indian shore, which at different localities supported a thriving population, has converted regions once populous and wealthy into an unhealthy desert. The delta of the Ganges, stretching for 200 miles through Bengal, and forming the rich plains of Bengal, is made up of the anastomosing branches given off by the Ganges and the Brahmapootra, and between the streams are islands of alluvial mud of very various heights, and frequently shifting their places as they are worn away by floods from the land or the ocean side. On the islands which form the lower delta, a rich vegetation gives shelter to wild animals of all kinds, and the tiger has banished the inhabitants from some parts of a region where man had maintained a footing against the ravages of the flood.

61. Formation of Deltas.—The formation of deltas requires some little consideration. The first requisite is that the mud-bearing stream should enter the sea so slowly that the detritus is not swept at once beyond the shore into deeper water. A tidal river with a rapid flow like the Thames is scoured out twice daily, and accumulations are not permitted to rest, far less to consolidate. A tidal stream, again, such as the Clyde, where the estuary is long and narrow, and the slope of the bed not great, allows a deposit of sediment which forms alluvial flats on either side, and thus offers the transition from the ordinary mud banks of a river to the delta properly so called. The commencement of a delta is at that point where the stream divides under the influence of slight obstacles, and its channels form a network embracing alluvial patches elevated above the surface of the waters. These patches are not all at the same level; for just as a single stream like the Po may build up its banks above the surrounding country, the channels through a delta may build themselves up so as to form conspicuous projections, not, however, permanent; and Mr Ferguson records that, within a very few years, the debris of a house which he had himself built has been covered to a depth of 30 feet, while on the new surface a village has arisen. By this alternate laying down and sweeping away, the general surface is, on the whole, steadily raised, and at the same time the seaward progress of the triangle continues. The name delta is borrowed from the Greek letter Δ, whose figure that of the river accumulations repeats; but it must be noted that this form is not peculiar to river mouth deposits, since, as the *cone de dejection*, it is the characteristic, fan-like pile of stones at the foot of a dry gulley, and the more flattened mass which the ravine lays down in the lake. The base of the triangle reaches the coast line, and then one of three events takes place: it pushes out seawards; it becomes arrested, or the river carries its mouths outwards without the rest of the delta pushing equally far. The seaward extension, possible only when coast currents are not strong enough to remove the sediment as it is brought down, is especially noticeable in the Adriatic, where the Po and Adige are steadily building their alluvia seaward; but the rate of advance has greatly increased within the last century, being accelerated by the means taken to protect the plains of Lombardy from being flooded. The rivers are now confined within high artificial banks, and the additional speed thus conferred carries the sediments further outwards. The growth of the Rhone delta within historic times is well known. Towns once on the coast are now, after nine centuries, two leagues from the sea, and the successive sand bars, thrown up parallel to the coast by the south winds, aids a process the results of which are made lasting by the infiltrated lime which gives solidity to the *Ager lapidosus*, the stony delta of the Rhone. It may give an idea of the approximate horizontality of subaqueous deposits to state, that off the mouth of the Rhone the bottom slopes southwards at an angle of less than 1°, or 1 foot in 66.

The arrest of the Nile delta at the present coast line is effected partly by the current which sets eastward along the African shore, and partly by the subsidence of the land which is still going on, and which permits the settlement of large parts of its sedimentary burden in the interior. The rapid descent of the sea bottom from 12 to 380 fathoms contrasts with the slow slope of the Rhone silt, and shows that the arrest of the delta is not of recent commencement.

The peculiar process by which the Mississippi terminates by mouths at the extremity of a long tongue of land, which spreads out like a bird's foot at the end, is the same as that by which it, like the Po and other rivers, builds up the levels of its banks.

62. Steppes, etc.—The plains have received particular names, or rather the native names are adopted into English on account of the convenience of thus recalling their characteristic features. The plains of Europe present great diversity; level or gently undulating, they are either grassy meadows or forest lands; in winter they may be flooded, and in summer more or less swampy. The Steppes of Eastern Europe and Asia, already treeless in the time of Herodotus, as they now are, support for a brief season a coarse but often tolerably abundant vegetation; but summer and winter convert them alternately into utter deserts and trackless snow plains, thus making it only too easy to understand how they have arrested civilization over an area of more than a million of square miles. The antiquity of these wastes is confirmed by Von Bär's observation, that the squirrels which throng the woods to the north of the Steppes in Russia are not found in the Crimean forests; the separation of the two woodlands must, therefore, have been remote. The Prairies of North America, the counterpart of the Steppes in the Old World, are great tracts of rolling ground, mostly meadow, but, like the Steppes, destitute of trees. Bounded westward by the Rocky Mountains and the desert land at their base, the Prairies pass eastwards into the forest lands of the Appalachians and the Atlantic shores. Northwards towards the Arctic Ocean, and southwards to the Mexican Gulf, the waste occupies an area of 3,000,000 square miles, and in South America an area of nearly the same extent is divided between the Llanos of Venezuela, the Campos Geraes of Brazil, the Pampas, and, farther south, the deserts of Patagonia; while, to complete the series of similar tracts, the deserts of Atacama, and the Salt Lake region of North America, may be mentioned. A careful comparison of the conditions under which these various regions are placed will show that to the dryness of the climate, to the long intervals between their rainfall, and in the extreme cases of the Sahara, Gobi, Atacama, and the like, to the total absence of rain, are their peculiar aspects due. Everywhere do we find forests intermingled with the steppe lands, but the trees follow the coast lines, and pass into the interior only along the river courses. The full meaning of this generalisation will only be intelligible after a consideration of the Atmospheric Currents in a subsequent chapter. But the sharp limitation of the forests to the perennially moist areas is nowhere better illustrated than in America. Passing westwards from Arkansas, in 35° to 36° north latitude, the forests here and there enclose patches of prairie land, which increase till the woods are only oases; the vegetation becomes restricted to buffalo grass, but in 106° west longitude the forests again commence. In South America the selvas or forest lands of the Amazon are in the line of the easterly winds, which blow from the Atlantic up the valley, the natural moisture of which is thus enabled to support a greater vegetation. The increased dryness of regions in which, artificially or by accident, the timber has been destroyed, as in Madeira, since the beginning of the fifteenth century, when the forests were burnt; the disappearance of springs after the woods have been cut down; the refilling of the lakes in Venezuela while the Creoles, during their struggle for independence, neglected the cultivation of the sugar cane; the formation of oases round the wells bored in Algeria by the French, these and many other instances might be cited in support of the view that the amount of moisture is the condition on which the steppe or the forest depends. Forests cannot be made to grow unless the climate is favourable, still less can they be forced on the Russian Steppes, where for long ages no timber has grown, because the climatal conditions are entirely changed. That region, like the interior of Africa, Australia, Asia, has its winds dried before they reach the interior, and the rainfall is at a minimum.

The Tundras or peat mosses of Siberia, and the heathy plains of Germany are usually grouped with the steppes; but the former, like the polders of Holland, the fens of England, are the result of a supply of moisture in excess of evaporation; while the latter are separated from the steppes by the forests, and require a greater supply of moisture, or, at least, are less able to retain it than extensive woods.

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CHAPTER III.

WATER.

Forms of Water—Cycle of Water—Imperfect Analogy of Aqueous and Atmospheric Envelopes of Earth—Effects of Cycle of Water.

63. Cycle of Water.—Water is the most important geological agent of which we have knowledge. The forms in which it effects change upon the surface of the earth are: 1°. Atmospheric moisture, whether insensible as vapour of water, or condensed into dew and rain, or, lastly, the condensed moisture solidified into ice. 2°. Rivers above and below ground; and under this heading come the glaciers, which, as moving rivers of ice, are denuding agents of great importance in temperate regions. 3°. The ocean.

It is difficult to say with which of these forms we ought to commence our investigation, for the the cycle is a continuous one, by which water is carried into the atmosphere and returns again to the ocean through the intermediate stages of rain and rivers.

64. Imperfect Analogy of Aqueous and Atmospheric Envelopes of Earth.—The endless movement of water stands in a somewhat peculiar relation to what, recalling M. Guyot's figure, may be called the other functions of the globe, and especially to that of the atmosphere. The currents by which the waters of the ocean travel to and fro, maintaining the balance of distribution, are determined by the winds, their direction and velocity being likewise affected by the earth's rotation; by evaporation, as a consequence of great local heat; by the tidal movement, and by the features of the coasts and sea floor. The atmospheric currents again are variations of the westerly winds, which form an oblate spheroidal shell round the earth, blowing at the level of the sea in high latitudes, at some distance above the earth at the equator, and this permanent movement is dependent on the earth's rotation. The parallelism usually taken for granted between the two fluids, air and water, which surround the earth, is therefore of the most imperfect kind, and could only be perfect if both elements formed spheres around a smooth globe which presented no projections, no features capable of causing deflections; and even then it would be further necessary that both fluids should present the same physical properties.

65. Effects of Cycle of Water.—By the movement of the ocean, heat and cold are distributed over extensive regions with a regularity and moderation due to the slowness with which its temperature is altered. Evaporation not merely supplies the needful moisture for the support of animal and vegetable life, it tempers the atmospheric currents—regulates them, so to speak. Acting on the land on which it falls, rain and rivers distribute chemical substances over larger areas, and prevent them from being accumulated in one locality. They carry off, slowly but surely, the materials which, spread over the ocean floor, are in their turn raised into dry land, and thus the subterranean movements are compensated. But these movements again owe their energy, at least frequently, to the presence of water. The circulation of water underground is a physical necessity of the broken condition of the strata, a necessity which results in the formation of springs, but for whose presence many regions would be uninhabitable for plants and animals, while the percolation of water charged with chemical solutions allows the deposit, in fissures, of minerals of various kinds. But part of this water, in place of returning to the surface, gets access to the underground reservoirs, and either originates or hastens the volcanic phenomena which we speak of as violent, and whose results we term catastrophes, because we cannot rightly estimate their place and proportion among natural phenomena.

SECTION I.

Proportion of Land to Water Surface—General Relations of Oceans—Deep Sea Soundings: How taken—Soundings in Atlantic; Mediterranean; Indian Ocean; Pacific—Form of the Ocean Floor—Deposits on Ocean Floor—Specific Gravity and Contents of Water—Pressure of Water—Temperature of Ocean—Colour of the Water—Luminosity of the Sea.

66. Proportion of Land to Water Surface: General Relations of Oceans.—The ocean, as has been stated, is four times more extensive than the dry land, and in the water surface of the globe must be reckoned the area covered by rivers and lakes on the dry land. Paradoxical as it may sound, the greatest water area in a continent is toward the high grounds where the feeders of the rivers are most numerous, uniting successively as they approach the low grounds, so as ultimately to form streams, which occupy a greater vertical and diminished horizontal area.

The oceans of the globe are the Pacific, the Atlantic, and the Indian, and these three are connected by the southern circumpolar ocean, their northern circumpolar connection being very much smaller. These different oceans are further subdivided into regions which, in general terms, correspond with the prominent features of the continents; thus the Atlantic Ocean is obviously divided into two basins, marked off by the constriction caused by the eastern projection of South America, and the western projection of Africa. The Pacific Ocean has its northern and southern basins roughly marked off by the Polynesian Islands, while the Indian Ocean shows a less complete division into two by the pyramidal mass of southern India. The minor areas which are referred to as seas, gulfs, and bays, belong to two categories: in the one case they are denudation valleys, in the other areas of subsidence. The German Ocean partakes of both characters, but it is pre-eminently an area of subsidence. The Red Sea is a denudation valley. The narrow channels which separate Madagascar from Africa, and divide Celebes and Lombok on the one side from Borneo and Java, outliers of Asia on the other, though doubtlesss to some extent valleys, are, by their antiquity and comparative depth, as well as by the distinctness of the animals on either side, entitled to a prominent place, if they cannot be ranked as co-ordinate with the great oceanic areas.

The Pacific Ocean covers an area of about 90 millions of square miles, the Atlantic occupies less than a third of that surface, the Indian Ocean covers a somewhat smaller area than the Atlantic. The Antarctic Ocean, in which all these great basins converge, is very imperfectly known, and the smaller Arctic Ocean is also even yet the subject of discussion and inquiry.

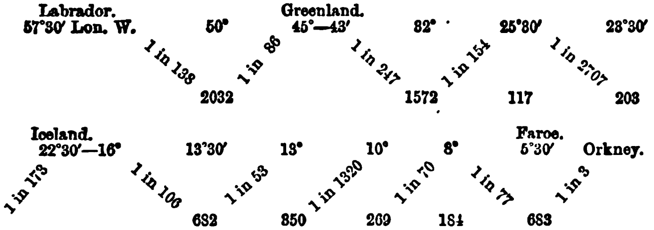
The Atlantic Ocean has in connection with it certain bays or recesses, more or less shut off from the general ocean space, and, in a few cases, entirely excluded from it. The North Sea is simply a bay of the old European continent, the Straits of Dover being a recently formed passage; the Baltic, with its branches, the Gulf of Finland, and the Gulf of Bothnia, is a valley which opens by a narrow channel into the North Sea; and from the Straits of Gibraltar eastwards a series of basins is defined, the first of which is bounded by the Italian Peninsula, Sicily, and Malta; the second, by the prolongation of the line of the Grecian Peninsula, to the east of which is the third; these three divisions of the Mediterranean likewise receiving lateral branches, such as the Adriatic and Archipelago. This last named shallow basin is connected with the sea of Marmora, and that again opens into the Black Sea, from which the Sea of Azof is shut off by a narrow channel, while the Caspian Sea and the Sea of Aral are obviously basins which have become closed off from the Mediterranean.

67. Deep Sea Soundings: How taken.—The soundings conducted in recent years have given important information as to the shape of the ocean floor. The method of conducting these observations deserves some attention. The simplest plan in still water is to let drop from a boat, whose position can be fixed by the oars, and by reference to objects on the land, a line with a weight at its extremity, the weight having an "arming" of grease or other adhesive substance by which evidence is obtained that the lead has reached the bottom, and what the character of the bottom is. The inventions of

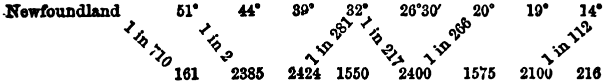
Brooke and others have resulted in instruments by which a portion of the bottom is removed and brought up for examination. The difficulties to be contended with in sounding are the uncertainty, first, as to whether the lead touches the bottom; second, as to whether the amount of line let out is much in excess of the vertical depth; and third, as to whether, supposing his lead sinks properly, the observer's position has shifted during the descent of the lead. This last difficulty is felt at sea only where no fixed objects are visible, the bearings of which can act as a guide, the sinking of the lead from a boat (which is, under certain circumstances, less liable to shift than a ship) diminishing, not removing, the chance of error. Experienced observers are, for the most part, conscious of the contact of the lead with the bottom, or at least of a momentary change of speed in the line as it passes through the hand, even in very deep soundings; but currents may sway the line, so that it describes curves which greatly exaggerate the depth. Nor does the absence of sand or other matters adherent to the arming prove that the weight has not touched ground; the "Hydra," "Bulldog," and other machines can scarcely come up empty if once they have touched soft soil. The record, "no bottom," on a chart, is only negative evidence, showing that the observation is imperfect, either because of the inexperience of the observer, or because currents have drifted the line, or, where the cleanness of the arming has been relied on, because the lead has touched hard and smooth bottom. Such records are especially untrustworthy when, as usually happens, they suggest enormous depths.

68. Atlantic Soundings.—The Atlantic Ocean has been carefully surveyed for the purpose of ascertaining the nature of the bottom on which it was proposed to lay the telegraphic cable; and, more recently, part of the northern basin has been carefully sounded by the Porcupine and Lightning Expedition, while the United States Coast Survey has contributed most valuable observations regarding the western area. The following analyses of the soundings across the N. Atlantic will show the general contour of that region.

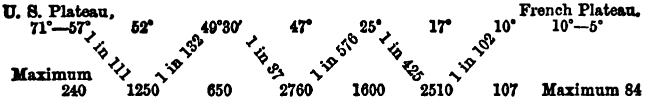
Section between Labrador and the Orkney Islands, by Iceland.



Section from Ireland to Newfoundland.



Section between United States and France.



In the northern section it appears that the curved line it follows traverses an undulating surface, the greatest depth of which is in 32° lon. W. To the south, the greatest depth is between 39° and 44° W., while the traverse from France to the United States gives the maximum soundings, 2760 fathoms, at 42° and 17°. A basin on the eastern side shows its greatest depth in 19° and 26° W.; but northwards the two basins are broken up by the banks of land forming the Faroes, Iceland, and Greenland, the whole ocean in this region being generally shallower. Iceland is a prominent peak of a long ridge which separates the eastern and western basins as far south as 40° lat. N., and which is of nearly uniform height for the greater part of its length. This feature of the sea floor is curiously parallel to the leading lines of heights on the American Continent, and if it should prove to be connected with the volcanic West Indian group, the relation would be one of great interest as increasing the number of meridional bands of disturbance connected by an equatorial band.

Some instruction as to the Atlantic depths may be obtained from the subjoined section between the Cape of Good Hope and England; but it must not be taken as true for any other than one line of soundings. The undulations here shown are remarkable, the alternations of deeper and shallower succeeding each other with singular regularity. St. Helena separates two slopes of unequal but gentle inclination, that to the south being at the rate of 1 in 150, that to the north reaching 2350 fathoms in 2° N. lat., that is, at a rate of 1 in 314. If a line of 5 inches be drawn, this inclination would raise a line representing it $\frac{1}{30}$ of an inch above the horizontal plane at one end, while, on the same scale, the slope between 2° and 37° N. lat. would scarcely cause an appreciable thickening of the pencil line. The last slope from 2600 fathoms to the English coast slightly misrepresents the facts; for the line of 100 fathom soundings, the limit of the British plateau, extends so far south that the inclination from its surface to the depth mentioned would be in reality about 1 in 15. The principal fact to be gathered from the above, and from other incidental statements scattered through books, is, that the South Atlantic and North Atlantic basins have a line of maximum depth which, in the latter area, bifurcates northwards, and probably does so in the south likewise, but the results of the Challenger Expedition will give more accurate information on this point.

SECTION FROM CAPE OF GOOD HOPE TO ENGLAND.

Cape of Good Hope.	2900	1800	2800	St. Helena	1600
	1 in 73	1 in 66	1 in 212	1 in 150	1 in 352
S. Lat. 34°	28°	26°	20°	12°	0°

2350	1400	2200	1610	2600	England.
1 in 94	1 in 880	1 in 176	1 in 179	1 in 106	1 in 27
2° N. Lat.	37°	41°	44°	47°	50°

69. Mediterranean Soundings.—The Mediterranean section is as follows:—

SECTION FROM GIBRALTAR TO EGYPT.

Gibraltar.	965	1585	234	Maltese Plateau.	160	2170	1100	1460	1890	Egypt.
	1in118	1in298	1in156			1in56	1in166	1in300	1in78	1in37
E. Long.	2°	8·30°	9·30°		15·30°	19°	24°	27°	28°	30°

To the three basins here shown a fourth should be added, the islands of Corsica and Sardinia dividing the deep trough between Spain and Italy. The Adriatic may at one time have equalled these two eastern depressions, but long ages of deposit from streams laden with Alpine detritus have converted that arm of the sea into a very shallow valley.

70. Indian Ocean.—No continuous sections of the Indian Ocean are accessible, but the following will give a general idea of the form of the basin, or valleys of its eastern and western troughs.

Section from Aden to Bombay.

Aden,		1470	1020	2170	125	Bombay Plateau.
		1 in 151	1 in 78	1 in 514	1 in 7	
E. Long.	45°	51·50°	52·30°	67°	71°	

Section from Ceylon to Penang.

Ceylon,	2340	1455	2320	545	950	59	Penang Plateau.
	1 in 48	1 in 252	1 in 81	1 in 15	1 in 158	1 in 85	
E. Long.	85° 30′	90° 30′	92° 30′	93° 35′	95° 30′	98°	101°

These two sections agree in representing the troughs as having their shortest slopes on the west, while their eastern shores terminate in submarine plateaux. That of Bombay runs out for over 100 miles before the depth of 100 fathoms is exceeded; while the Penang plateau has less than 70 fathoms at the same distance from land.

71. Pacific Ocean.—Of the Pacific there are no soundings sufficiently connected to furnish satisfactory tables, but it seems certain that nowhere has a greater depth been found than 3000 fathoms; so far, therefore, as our present knowledge goes, the oceans have a remarkable uniformity in their vertical measurements. Such observations as are reliable will be found in a subsequent section, under the heading "Temperature of Ocean."

72. Form of the Ocean Floor.—It has been customary to speak of the sea bottom as the counterpart of the land as regards its contours, the assumed resemblance being a part of the notion already alluded to, that the ocean and the air were parallel in their relations. But it is now certain that this resemblance holds good only for moderate depths. When an estuary widens, it retains the valley form which it once had as a result of its denudation when exposed as dry land. When we pass to depths exceeding 100 fathoms, the sea floor presents inequalities, but these are of a very gentle kind; no deep chasms, no abrupt descents, but long undulations, and great areas the surface of which, when drawn on a true scale, entitles them to be regarded as plateaux, and to be compared with justice to that recent sea bed, the Sahara. It is difficult to account for this in a satisfactory way. It is true that the sea bed, once the surface of dry land, has undergone marine erosion as it sank, and that the process was repeated during the oscillations which preceded the final submergence of such an ocean floor as that of the Atlantic. The plane of marine denudation thus formed would, so far as known, undergo no subsequent change, since the movement of water at great depths cannot be, and is as a matter of fact known not to be such as to produce any denudation, especially as it had no pebbles to carry along and use as grinding tools. Even granting the extreme power that has been claimed for the Gulf Stream, this mass of water can only exert its power over a limited area, and its effect would be to create those features whose absence is so remarkable. It would be impossible to imagine a series of gulf streams, or similar currents, to have planed down the floor of all the great oceans; and it is unnecessary, since the denudation during descent would account for much at least of the result. The subject is a difficult one, but the explanation suggested is the best at present available. The student must again be cautioned against forming his opinions from sections in which the horizontal and vertical measurements are not on the same scale.

73. Deposits on Ocean Floor.—Another assumption has also been disproved by recent research, namely, that the sea floor at a certain distance from land is bare and rocky. This has been found in a small number of cases; but the sea floor is almost universally covered by a layer of fine materials, for the most part organic in their origin. The oaze of the Atlantic has already been spoken of as a fine calcareous mud, representing the debris of animals covered with tests, and containing also the siliceous cases of other similar organisms.

The Indian Ocean and the Pacific have yielded at their greatest depths similar materials, though in the Red Sea and Indian Ocean the sand blown from the deserts has contributed inorganic matter, and the ashes of volcanoes, slowly settling, have furnished a small amount of felspathic ingredients. But allowing for such admixtures, which would, of course, be greater in proportion to the vicinity of land, recent observations bear out the generalisation that limestones, not consisting exclusively of coral, are formed in deep water, and that their horizontal area and vertical thickness are in the direct ratio of their distance from shore.

74. Specific Gravity and Contents of Water.—Perfectly pure water may be regarded as only an artificial compound, the normal condition of all known waters being to contain varying quantities of other chemical substances; and we are justified in calling this normal, since on the admixture depends the importance of water in the physiology of the earth. The rain as it descends absorbs carbonic acid gas and ammonia, in quantities varying with the season, being less in winter when the decomposition of organic substances is least. Thus, on reaching the earth, the water is prepared to act on the surface on which it falls, and to minister to vegetable life by the nitrogenous matter it contains. The water of rivers varies in composition according to the rocks over which it flows, and the amount of organic matter furnished to it by surface drainage. The Thames drains a region of which the chalk is a principal rock, and at Kingston the waters of the river are found to contain 19 grains of dissolved matters per gallon. The substances which thus pass down, invisibly to the eye, are carbonates of lime and magnesia, sulphates of lime, potash, and soda, chlorides of sodium and potassium, silica, and traces of alumina, iron, and phosphates. Mr. Prestwich estimates the total quantity of solid matter thus carried away in solution at 548,230 tons per annum. Of the 1502 tons which are thus daily carried past Kingston, carbonate of lime constitutes two-thirds, or about 1000 tons, sulphate of lime 238 tons. This estimate is apart from the solid matter, mineral or organic, which is held in suspension, and which may be taken at 1·68 grains per gallon, or (the daily discharge of the river at Kingston being 1250 millions of gallons) 300,000 lbs., or 134 tons in the twenty-four hours, being 48,910 tons in the year. This example shows the greater importance, from a physiological point of view, of the invisible contents of water, and indicates the function of water as a distributer of fresh materials. But for this source of supply, chemical equilibrium would tend to be reached; the new matter, however, maintains chemical action and all those processes, organic and inorganic, which make up the life of the earth. In 100 parts of sea water 96·473 are water, the remainder salts, namely, chloride of sodium, magnesium, and potassium, bromide of sodium, sulphates of lime and magnesia. Carbonate of lime is not mentioned, its quantity being very minute, though in the immediate vicinity of a calcareous coast, as in the English channel, it forms ·0057 parts per 100 of water. The reason of the small proportion in sea water compared to that poured in from land, is doubtless the rapid using up of it by animals and plants, the coral reefs and the more minute, but perhaps more important, crustaceans and shell fishes. Taking Bischof's estimate that the Rhine at Bonn would supply with lime a mass of oyster shells covering four square miles to a depth of a foot, it is obvious how readily the lime must be removed from the sea at all points. The average proportion of chloride of sodium may be taken as between 2 and 3 parts per 100; but the proportion is liable to increase or decrease, in the one case by evaporation, in the other by excess of fresh water. The Dead Sea illustrates the extreme of saltness, the Black Sea furnishes an example of a basin receiving a large supply of fresh water. The following table gives the specific gravity of water at various localities:—

Northern Ocean,		1·02757 1·02664
Southern Ocean,		1·02919 1·02676
Under the Equator,		1·0277
North Pacific,		1·02548
South Pacific,		1·02658
Indian Ocean,		1·0263
Mediterranean,	East	1·0293
	West	1·0286
Black Sea,		1·01418
Red Sea,	North	1·0297
	South	1·0272

These figures must not be taken as absolutely correct; for in the Pacific, as an instance, the observations are few, and though the lower specific gravity in the north, as compared with the south, agrees generally with the observations in the Atlantic, the difference between the Atlantic and Pacific is not necessarily constant, the observations in the latter ocean being neither sufficiently numerous nor made far enough from the land to justify the generalisation that the waters of the Pacific have a lower specific gravity than those of the Atlantic. We must again look to the scientific explorations now in progress for the settlement of this difficulty. That the specific gravity of the surface waters may be lower than that of deeper water, was first inferred from the observation of Edward Forbes, who explained the death of many specimens dredged up, by supposing them to have been killed by the fresher surface waters. Difference of pressure had probably more to do with this phenomenon; but Buchan quotes Dr. Rankin's observation, that the density of the water at the mouth of Loch Fyne sank from its normal 1·0250 to 1·0210 after a heavy fall of rain, and in less than twenty-four hours regained its usual value. Apart from exceptional cases, where the sudden melting of great masses of ice has flooded the adjacent sea with fresh water, or a few constant phenomena, such as the influx of the fresh waters of the Amazon and Orinoco into the ocean, it may be remarked that the lagoon waters of some atolls, though they rise and fall with the tides, the sea filtering through the coral mass as through a sieve, are fresh; nor is this remarkable, since it is pointed out by Wilkes in his report of the United States Exploring Expedition, that the surging up and boiling over of a hot current, intercepted by a coral barrier, gives rise to almost constant precipitation of rain. The specific gravity of surface water has been found to be increased during the prevalence of high winds, an unexpected result, since the surface waters are warmer after a storm, their motion being converted into heat. The density of water below the surface is not uniform; ordinarily lighter water floats over denser, but the relation may be reversed if the lighter water is introduced as a swift stream; thus the fresh water in some cases underflows the sea water in tidal rivers, and water of specific gravity 1·0265 has been found at 73 fathoms, while above it the specific gravity was 1·0270, Wyville Thomson found at 49° 12′ N. lat., 12° 52′ W. long., that the density increased from 1·0272 at 50 fathoms to 1·0277 at 800 fathoms; while at 54° 28′ N. lat., 11° 44′ W. lon., the surface showed 1·0280; the bottom (1425 fathoms) showed 1·0269; and at another point the difference was, surface, 1·0280; bottom (664 fathoms), 1·0272, the evaporation of the warmer surface increasing its density.

Fresh water heated to the boiling point and allowed to cool, contracts as it cools down to 4°C. (39·2°F.); if the temperature is still further lowered, it again expands till it reaches 0°C. (32°F.), when it freezes. But salt water thus treated does not attain its maximum density till it has reached − 3·67°C. (25·4°F.), the freezing point of undisturbed, − 2·25°C., that of disturbed sea water. While fresh water therefore expands under opposite extremes of heat and cold, salt water expands from its freezing point uniformly to its boiling point.

75. Pressure of Water.—A column of water 35 feet in height is equal to a column of mercury 30 inches in height, and these two represent the pressure of a column of air five miles high, of equal density throughout. At the depth of a mile, the pressure of the water equals that of 152 atmospheres, and its bulk is reduced by $\frac{1}{144}$; at greater depths the pressure increases, so that at twenty miles the reduction in volume would be $\frac{1}{7}$. But this acts injuriously only on compressible bodies; thus air is greatly reduced in volume, but just as animals on the dry land are not injured by the weight of the atmosphere, so the ocean pressure does not affect those animals whose bodies are supported inside by the same element as that which presses on them outside: the pressures being equal, the animal is in equilibrium. Thus animals are enabled to live at great depths, shell-fish having been brought up from more than 2000 fathoms, while the same species are found living also in very shallow water. But though uninjured by pressure its sudden removal is fatal, since the animals from great depths reached the surface dead or dying, just as man would be killed by passing through the upper regions of the atmosphere.

76. Temperature of the Ocean.—The waters of the ocean never sink below − 3°·5C. (24°F.), and very rarely rise at the surface above 34°C., this exceptional temperature being recorded near Aden.

Water has the highest specific heat of any known substance; thus, if a pound of mercury and a pound of water are both raised 1°, it requires thirty-three times as much heat to do this for the water as for the mercury, and if these are cooled 1°, the water sets free thirty-three times as much heat as the mercury. Tables have been constructed showing the specific heats of different bodies. Taking the specific heat of water as 1000, that of mercury is 33, or, as it is also written, water 1·000, mercury 0·0333.

The following table shows the specific heat of equal weights of the most important substances, the determinations being those of Regnault, cited by Tyndall:*—

Water,	1·000		Lead,	0·0314	
Air,	0·237		Magnesium,	0·2499	
Oxygen,	0·218		Mercury,	0·0333	
Nitrogen,	0·244		Potassium,	0·1696	
Hydrogen,	3·409		Silicon,	0·1774	
Carbon,	0·2414		Silver,	0·0570	100
Diamond,	0·1469		Sodium,	0·2934	
Copper,	0·0952	74	Sulphur, native,	0·1776	
Gold,	0·0324	53	Tin,	0·0562	15
Iron,	0·1138	12	Zinc,	0·0955	

The figures in the second column give the relative conductivity of the metals for heat.

The relation of land and water as regards heat, is such that it requires four times the heat to raise water to the same temperature as land; the quantity of heat therefore retained by the sea is greater than that retained by the land, hence the sea never rises so high nor sinks so low in temperature as does the land. A glance at the above table shows that capacity for heat does not mean conductivity, the molecular transfer by which each atom passes on the motion to its neighbour being dependent on different conditions from those of the specific heat. Water, though having the highest specific heat, is a very bad conductor of heat, the raising of a mass of water to the same temperature throughout being effected by convection, or the transfer of masses of heated water from place to place, not the transfer of motion from atom to atom.

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* Tyndall. *Heat as a Mode of Motion*, Chap. V.

It will be apparent from what shall be said hereafter regarding currents, that no general statements can be made which shall profitably represent the general temperature of an ocean. The observations must be studied, map in hand, and for each particular tract that has been carefully explored, if it is desired to have a thorough knowledge of the surface variations. From what has been said, it will not be unexpected that the surface temperature of the sea does not follow that of the air in contact with it. To illustrate this, a table is subjoined, extracted from the deep sea soundings of the "Porcupine." The noonday observations have been taken for the month of June 1869, and they are arranged, not in chronological order, but according to degree of west longitude, between north latitudes 51° and 54° 30′. The upper of the two lines of figures represents the sea temperature, the lower that of the air. All the temperatures are centigrade.

Valentia,	12·7°	15·
10° 59′	12·2°	12·5°
	13·3°	14·7°
11° 34′	11·6°	13·9°
11° 45′	11·1°	10·5°
11° 52′	12·5°	12·7°
12° 26′	11·9°	14·4°
12° 50′	12·2°	15°
12° 53′	14·4°	16·4°
13° 14′	10·6°	12·7°
13° 23′	12·2°	15°
13° 48′	12·2°	13·3°
15° 08′	12·2°	10·8°
15° 24′	12·7°	12·2°.

In 1870, Irminger gave tables showing the alternations of streaks of warmer and cooler water between Greenland and Fair Island. These streaks vary in position and breadth, and represent the interlacement of the southern warmer and northern colder waters. The Atlantic explorers have shown that the temperature of the sea sinks, but not uniformly, till a constant temperature of 0°C. (32°F.) is attained at great depths. But, as will be more fully stated afterwards, this constant temperature is not everywhere obtained; for the warm waters may displace the colder in the shallower parts, especially where channels exist between outstanding land masses, and the bottom temperature may thus be that proper to a lower latitude, while in the same parallel of latitude very different bottom temperatures *co-exist.* Captain Shortland's observations of surface and bottom temperatures in the Indian Ocean, between Bombay and Aden,* may be thus summed up:—

ON THE BOMBAY PLATEAU.

Temperature of Air.	Depth.	Surface Temperature.	Bottom Temperature.
22·6°–24·7° C.	11–51 fms.	22·5°–26·1° C.	23·1–25·8 C.

But the depths and temperatures are not regularly graduated; thus the highest surface and bottom temperatures, 26·1° and 25·8° respectively, correspond to a sounding in 45 fathoms, and the lowest are in the shallowest water. Between Bombay and Aden, the mean temperature of 15 days between 28th January and 12th February 1868 was 24°C., the surface temperature 23·8°, and at 2170 fathoms 0·83°C. Captain Shortland considered that variations in surface temperature were not appreciable at greater depths than 100 fathoms, and that the constant temperature might be said to begin at 1700 fathoms. These results agree generally with those of the Atlantic Expedition, from which it appears that solar variation does not produce marked effects beyond 50 fathoms, and the constant temperature begins about 1000 fathoms. The rate at which the temperature sinks is shown in the following series of observations, taken two miles north of the equator, in 22° 16′ W. lon., the temperature of the air being 26·6°C.

Depth in fms.,	0	300	400	1000	2040
Temperature,	27·2° C.	6·44° C.	5° C.	3·3° C.	1·64° C.

A remarkable anomaly is presented by the Mediterranean, in which the temperature sinks during 100 fathoms to an average of 13° C. (55·5° F.), and this may be taken as the mean temperature of the Mediterranean below 100 down even to 1500 fathoms. The Red Sea is even more completely land-locked than the Mediterranean, and its shores have a higher average temperature. The bottom waters have a mean of 21·6°C. (71°F.); now as the Red Sea does not exceed 1700 fathoms in depth, its temperature is that of the water between 50 and 100 fathoms in the Indian Ocean. Solar radiation therefore, doubtless, has an important part in raising the temperature, and to achieve this great heat it is obvious that the horizontal movements must be very slow.

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* *Journal Geographical Society*, 1871, p. 58.

Mr Prestwich has collected and tabulated observations in the Atlantic and Pacific which are here condensed, the latitude but not the longitude of the stations being given.

TEMPERATURES OF ATLANTIC.

Latitude	42°N.	29°N.	7°21′N.	4°25′N.	15°3′S.	25°10′S.	29°33′S.	32°20′S.	28°12′S.
Depth (ft.)	4688	8399	3030	6037	7200	5315	6310	6444	2000 ?
Surface	17·7°C.	24·4°	26·6°	27·1°	25°	19·6°	19·1°	21·9°	16·9°
Bottom	6·6°C.	6·1°	2·2°	5·9°	4·1°	3·1°	2·1°	2·5°	3·1°

TEMPERATURES OF PACIFIC.

Latitude	51°34′N.	28°52′N.	18°5′N.	4°32′N.	0°	21°14′S.	32°57′S.	43°47′S.
Depth (ft.)	5741	3600	4261	12271	6000"	5500	4692	6400
Surface	11·7°C.	25·5°	24·7°	27·2°	30°	27·2°	16·3°	7·5°
Bottom	2·5°C.	9°	4·8°	1·7°	2·5°	2·2°	5·4°	2·3°

From the bottom temperatures a deduction of 2° or 3° has to be made for error due to pressure on unprotected instruments, but these figures show that a mass of water of low temperature crosses the equator, and in the Atlantic at least, the connection of the Arctic and Antarctic Oceans is probably due to the passage northwards of southern cold waters; for, as will be explained in describing the N. Atlantic currents, the Arctic cold waters pass to the west side, and are separated from those of the Bay of Biscay by a mass of water warmer than either. The Arctic current enters the Gulf of Mexico beneath the warm outflowing stream, but the bottom temperature 4·16° C. between Cuba and Yucatan must have a southern source. While the annual variations of temperature cease to be felt at about 100 fathoms, the daily variations do not probably extend beyond 10 fathoms; but the influence of currents, and of local and temporary disturbances due to configuration of the land, and to storms, forbids our acceptance of such generalisations from the comparatively scanty data at our command. To the category of premature inductions must also be referred the conclusion of M. Aimé, that the average temperature of the sea at a distance from land is 18°C. (64·4°F.), that of the air being 18·22°C. (64·8°F.).

77. Colour of the Water.—Tyndall has shown that water and aqueous vapour have the same absorptive power, and he regards the blue colour of distant hills as deep in proportion to the aqueous vapour in the atmosphere. It is also a well known fact that the blue colour of the sea is intense in proportion to its saltness, and that the fresh water lake of Geneva is of a very deep blue. The blue of the atmosphere, and of the Lake of Geneva, might be capable of explanation by reference to the fine particles of solid matter with which both are charged, these particles reflecting the short blue waves of light most readily. But the waters of the open oceans do not contain these particles to the same amount, and in passing from open sea to land, the blue gives place to green, and that to greenish yellow; while close to the shore, as the solid matters increase in quantity, the tint becomes that characteristic of the rocks or soil whence the fine detritus is derived. The problem is not yet near a solution, and the observations must remain in seeming contradiction till the key to their harmony shall have been found. Closely associated with colour is the permeability of the sea to light. Though it cannot be supposed that the open ocean contains as many suspended particles as a glacial lake, analogy would lead us to expect that it contained such particles perhaps even more abundantly than the atmosphere. The density of the water, and this fine cloud, would together form an obstacle to the passage of light, and there is reason to believe that the actinic rays are arrested at a comparatively short distance beneath the surface. Nordenskiold found a sensitive plate unchanged after twelve hours' exposure at the bottom in 79° 54′ N. lat. amid luxuriant seaweeds, the temperature of the bottom was 2°C. Plants, too, are not met with at greater depths than 200 fathoms, and as their power of liberating oxygen is associated on land with abundance of light, their paucity between 50 and 200 fathoms, and their absence beyond the lower limit has been held to favour the view that light has very sparing access, if any, to the deeper waters. But Mr J. Y. Buchanan has ascertained that sea water has a very retentive grasp of carbon dioxide (carbonic acid), and this, rather than defect of light, may account for the early disappearance of plant life. This question likewise awaits further investigation, and it is useless to speculate in the *absence of data.*

78. Luminosity of the Sea.—The so-called phosphorescence of the sea has given rise to as much imaginative scientific as poetical writing. The tints are uranium green, violet, lilac, crimson lake, rarely azure, still more rarely white, and they appear as steady stars, as lambent light moving along the bodies of star fishes and other animals, or as intermittent flashes. Various microscopic bodies possess this property, the source of which is obscure, and equally so are the conditions on which its often fitful display depend. Probably variations in temperature, and stillness of the water, permitting or forbidding the approach of the minuter organisms to the surface are the most important; the phenomenon is often well developed during magnetic storms.

SECTION II.

Movements of Water—Waves—Tides—Tidal Wave not a Wave of Translation—Progress of Tidal Movement—Currents: Streams, Drifts, Indraughts, Equatorial Drift—Gulf Stream and N. Atlantic Basin—Movements beyond 45° N. Lat.: their Cause—Rennel's Current—Mediterranean Currents—Baltic—N. African Currents—Sargasso Sea of N. Atlantic—S. Atlantic—Antarctic Drift—Pacific Currents—Pacific Equatorial Drift—Australian Currents—Currents of Indian Ocean—Red Sea.

79. Movements of Water.—If the globe were uniformly surrounded by a sphere of water subject to no external disturbance, the water would move from west to east with the velocity proper to each parallel of latitude. But this theoretically simple motion is disturbed by the projection of masses of land; by the unequal temperatures of the oceans; by the influence of steady or occasional winds; by the introduction of fresh water streams from the land; by subterranean movements; and by the influence of the sun and moon, to which are due the phenomena of the tides.

80. Waves.—Water acted on by the wind is heaped up to leeward, the friction between the moving air and the water *carrying forward* the particles of the latter till they overpass the limit of equilibrium and fall over, the phenomenon being seen in its simplest form where wind passes over dry sand. A continued wind gradually involves successively deeper layers in this forward movement, till finally a disturbance is created which survives for some time the existence of its cause. Two different kinds of movement are unfortunately represented by the word wave, and these must be distinguished. A wave is a pulsation or vibration among the particles of a fluid; the particles tend apart and again return; there is no displacement in any except a perpendicular plane. Water thrown into vibration, say by an impulse from below, starts upwards; and if the blow be violent enough, a portion springs into the air. If the force of the blow is not sufficient to overcome the cohesion of the liquid, the disrupting tendency of the vibration is masked, but it still finds compensation in sinking as far below its original level as it had been raised above it. A wave of water consists of two points of rarefaction and one of compression—the rarefaction points being at the crests of two pulses, the compression point at the lowest point of the intervening trough. Pulse is here used in the sense which it has in acoustics, but the sound-wave has its compression point at the apex of the pulse, its rarefaction point in the interval between the two pulses. The length, then, of a wave is from crest to crest, the height from crest to trough. But it must not be imagined that there is no horizontal movement; the particles of which the wave is composed revolve in circles, returning to the spot whence they started. The length and height of waves vary from the slightest ripple to those in whose trough a large ship may be cradled, or whose crests are so far apart that a long vessel lifted on the summit of one has its back broken. The circles in which the particles revolve are larger in proportion to the magnitude of the disturbance, or, in other words, to the disruptive tendency imparted to the pulse of water. Whatever tends to compress the water diminishes the diameter of the vertical circles which the particles described; hence the depth to which wave motion is propagated depends on the amount of disturbance which, if slight, only elevates and rarefies a small layer of water; if great, rarefies a thicker stratum. It follows from what has been said, that a column of water, starting from a position of rest, describes a series of oscillations before returning to rest; the limit of oscillation is the diameter of the circle in which the individual particles revolve, and infinitely minute as the oscillation may be, it confers the tendency to actual translation or forward movement which was alluded to in the first lines of this paragraph. The rarefied surface layer, carried forward by a wind strong enough to overcome its cohesion, exposes a fresh surface to be rarefied by elevation, and thus the wave and its oscillation become propagated downwards. The largest waves recorded are those whose height was estimated at between 30 and 40 feet from trough to crest, but masses of inferior size, when arrested by an obstacle, possess enormous force. The waves of British seas probably never exceed 8 feet, even off the west coast. But this height may be exceeded close to shore, and a wall of water 8 or 10 feet high, pushed over by the wind, strikes on the land with formidable violence. The pressure on the square foot has been calculated for the Atlantic breakers on the west coast of Scotland at 611 lbs. in summer, 2086 lbs. in winter; and a pressure of about 6720 lbs. on the square foot was necessary for the ground swell to cast its spray over the Bell Rock lighthouse, on the east of Scotland, the height of the tower being 112 feet. The gentlest wind ripples, and the waves caused by other influences than the wind, are even curves of well-nigh symmetrical form; the spectator may look towards or look after the wave without seeing an appreciable difference; but with the velocity of the wind the steepness of the leeward face of the wave increases, the front being a dark green cliff, the back of the wave a long curve of smooth blue or green water, a distinction well enforced by Ruskin. Waves whose crests are torn off by the wind, and which tumble over in foam, are called breakers; and these on fixed obstacles, as a river bar or fringing reef, maintain a constant mass of foam—the surf—which it is dangerous and sometimes impossible to pass. When a wave has broken on the shore it rolls back, the slope of the beach increasing the fall of what corresponds to the trough of a wave. In caves, the wave dashed to the roof crushes out the air, and when it sinks sucks down what may be loose in the roof, thus tending to produce bullers or blowholes, opening vertical shafts some little way from the edge of the sea-cliffs. After a storm has subsided, the wind-driven waves with steep leeward faces disappear, and the agitation survives in proportion to the severity and continuance of the storm. The ground-swell, as this residue of a storm is called, testifies to the depth to which the waves have been propagated, while its pressure suggests the force of the previous motion. The transporting power of waves on the shore, both in their forward movement and in their backdraught, is very remarkable. Blocks of 504 cubic feet (about 40 tons weight) have been carried 5 feet; blocks of more than 200 tons have been turned over and broken; masses of 20 tons have been carried 80 or 90 feet. Of course, these masses are of easier transport in water, but they are still remarkable proofs of the power of water. A more gentle but more important influence of waves is seen in the travelling of beaches, the stones of which move forward according to the set of currents and wind-waves, become piled up against an obstacle, and often render vain any effort to check their progress.

81. Tides.—That the sun and moon are associated with the phenomena of the tides is well known; that the method in which these phenomena are produced is known does not seem so certain. The discussion of the tides belongs properly to astronomy, but it is necessary to indicate here the bearing of the problems it involves on the history of the earth. Twice every day the waters of the sea rise and fall, or flow and ebb, on the shores at high and low tides; the interval between high tides is 12½ hours (nearly), so that each successive tide is later than that before. Once every month the difference between the level of high water and low water is at a minimum, and the difference gradually increases till the level of high water is higher, of low water lower, than at any other time. These monthly minimum and maximum tides are neap and spring tides. They correspond to, but do not coincide with, the positions of the sun and moon relatively to the earth. The attraction of the moon is greater on the particles of water immediately beneath it than on the centre of the earth, still greater than on the surface *particles* on the opposite side of the earth.

The same is true for the sun, but the more powerful attraction of the sun is counterbalanced by its greater distance, and the tidal elevations due to moon and sun are in the ratio of 5 : 2. As each planet forms a tidal protuberance on the side of the earth towards and away from it, so a corresponding flattening occurs midway between the protuberances. Now the moon describes her apparent diurnal circuit in about 25 hours, and the sun in 24: the solar tides are therefore at 12 hour intervals, the lunar at 12h. 24m. intervals; thus the solar tide will overtake the lunar. If, therefore, the attraction of both planets affects the same points, as when the sun and moon are on the same or opposite sides of the earth, the protuberances due to each will coincide, and the rise and fall of the tides will be at a maximum; if the sun and moon are so placed that the long axes of the spheroids formed by their tidal protuberances are at right angles to each other, the solar protuberance will coincide with the lunar flattening, and the opposite influences reduce the difference of tidal elevation to the minimum, giving neap tide. The height of the spring tides will obviously be affected by the distance of sun and moon from the earth. Again, as the orbital planes of sun and moon are oblique to the equator, and as the attraction of these bodies is on the point immediately beneath, the northern or southern declination of the sun and moon will also affect the height of the tide at any point. But it must be remembered that the sea thus raised and depressed is not a perfect sphere, but broken up by the land into irregular spaces; that there is frictional resistance to the motion of the water, whose particles rub against each other and against the earth, and that the earth itself rotates. The tendency of sun and moon to produce the theoretical tide is not fully realised. The tidal elevation does not coincide with the passage of sun and moon across any point, neither does it represent the whole elevation due to one of the planets; but the joint heights of the two elevations give a maximum at a point intermediate between them. Hence the length of the tidal wave varies as the two attractions approach or recede from coincidence, the variation being known as the priming and lagging of the tides. It is *delayed by friction*, so that the spring tide, when the sun and moon are in conjunction or opposition, is later than new or full moon by an interval of more than 12 hours and less than 3 days. This frictional resistance tends to retard the rotation of the earth round its axis by 22 seconds in a century (Adams, Tait, and Thomson). This retardation, it is supposed, would in time reduce the earth to the condition of the moon, turning only one side towards it. On the decreasing rotation of the earth, Sir W. Thomson rests his speculations as to the former condition and probable future of the earth.

82. Tidal Wave not a Wave of Translation.—Reverting to the definition of a wave (Art. 79) as a pulsation or vibration of the particles of a fluid which tend apart and return to their previous relations, the tidal movement in the open ocean fulfils this condition. The particles of the water are raised up and let down, just as the bits of paper rise and fall as the heated sealing wax is carried over them. The tidal wave is a *superficial shape* of the water, and high and low water occur according as the upper or lower portion of this elevation occurs on our coasts. But when water is heaped up in any place in which it cannot freely resume its customary form, it is converted into a wave of translation, which either travels swiftly over shallow water, or passing through a narrow channel forms a rapid current. The estimated rise of the tidal wave in open ocean, as in the Pacific, is about 2 feet, the observed seems to give a mean of about 9 inches, and the difference is due, it has been suggested, to a similar movement in the solid earth itself, an hypothesis which must as yet be received with caution. But the observed height of the tidal rise on the shores of continents greatly exceeds this amount, reaching its maximum in the Bay of Fundy, into which a mass of water 100 to 120 feet deep is poured. The Bore of the Severn, the Hoogly, and other great rivers, is the tidal wave heaped up in a narrow passage and rushing forward in a huge roller which breaks into foam. Where long flats shoal the water for some distance, as in the Solway, the tidal wave rushes forward with velocity as a great bank of water.

83. Progress of Tidal Movement.—The tides travel with *various speed. In the* open ocean swiftly, but in narrower seas with less speed and greater mass; and frictional resistance makes its effects very obvious on a chart showing the co-tidal lines, retardation being obvious on the east side of the north Atlantic basin, and in the Atlantic, as a whole, compared with the freer Indian Ocean. The increase of velocity due to local circumstances is illustrated by the eagre or bore of the Tsien-Tang in China, the tidal wave advancing up the river for 80 miles at the rate of 25 miles an hour. The strong streams through the Pentland Firth and similar confined channels are examples of extreme velocity; but it is only in such cases as the *cul-de-sac* of the Bay of Fundy that the ebb tide can have any important power as a denuding agent. The Atlantic and Indian Oceans, in which the tides advance from south to north, evidently do not illustrate the antipodal character of the tides, and in them the necessity is very clear for ascertaining accurately what is known as the Establishment of the Port. By this is meant the interval between the passage of the sun and moon across the meridian of the port and the occurrence of spring tide. This interval varies in every locality, and Herschel urges the necessity for distinguishing with care between the slack water, when the tidal wave does not run in either direction, and the time at which the tide ceases to rise or fall.

84. Currents, Streams, Drifts, Indraughts.—The movement of a body of water in a definite direction, whether the direction and velocity are constant or liable to variation, constitutes a current, and by means of these an oceanic circulation is maintained, the heat of tropical, the cold of polar regions being interchanged and distributed. Currents are of very different magnitudes, and it is as difficult to classify them by size as by reference to their probable origin; but in this and the following paragraphs it is proposed to consider only the great currents whose constancy and magnitude render them as important from a climatal as from a nautical point of view. From what has been said of the tidal wave, and from the investigation of the causes of the great currents, it will be easy for the student to understand the existence of the minor, local, and often extremely uncertain currents, the enumeration of which belongs to the province of Descriptive Geography.

The discussion as to the origin of currents has brought into prominence two phrases: current and indraught; the former is used by those who ascribe the primary movement to the influence of prevailing winds, indraught being the opposite movement, by which equilibrium is restored. Those who trace the oceanic circulation to differences of temperature regard all movements as currents, and urge that a difference of speed is not sufficient to define an indraught. But no definition by typical characters is here attempted, the terms are used to indicate a difference of origin; the primary current having its impulse imparted from without, the indraught being secondary to and dependent on the existence of the primary movement.

Currents are usually divided into drifts or the primary wind movements, and streams or modifications of the drifts effected by features of the land or of the sea bottom; the indraughts are supplementary to both.*

85. Equatorial Drift.—The equatorial drift, commencing south of the equator, off the west coast of Africa, crosses the Atlantic, and, spreading out westward, splits on Cape St. Roque, one branch passing southwards along the Brazil coast, the other following the land north-west towards the Caribbean Sea. The St. Roque Current has an average velocity of 30 to 40 miles a day, the speed of the equatorial drift being on an average 20 to 35; but before entering the Caribbean Sea, a speed of 80 miles may be attained. It follows the north-westerly bend of the coast, sweeps the waters of the Amazon and Orinoco along with it, and enters the Gulf of Mexico through the Straits of Yucatan. A part of the current is arrested by the Mosquito coast, and forms a backwater which sweeps eastward round the bay to rejoin the main stream off New Granada. The chief part of the current spreads over the Mexican Gulf, and returns towards Cuba, where it is joined by a portion which clung to the Cuban coast, the united stream rushing through the Straits of Florida as a great river of warm water 30 miles broad, 2100 feet deep, and with a surface velocity of 4 miles an hour. The temperature of the equatorial drift is 23°C., the initial temperature of the Gulf Stream is 30°C., the difference representing the amount of heat received in the Mexican Gulf. In the equatorial region a bottom temperature of 0°C. has been found constant, and in the Florida Straits a temperature of 4·5°C. proves that cold water underlies the warm.

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* In speaking of ocean currents, eastward, westward, northward, and southward are invariably used to indicate the direction in which they move; and the direction whence the winds come is indicated by the ordinary terms. But the student must remember that in the language of navigation a northerly wind comes from the north, but a northerly *current sets towards* the north,

86. The Gulf Stream and North Atlantic Basin.—The mass of waters flowing past Cuba meets the equatorial drift, and is deflected northwards through the Straits of Bemini, following thereafter the curve of the coast as far as Cape Hatteras, and joining the eastward drift at the 40th parallel, its velocity there being 30 miles a day. It is separated from the land by a belt of water of varying breadth, but which gradually widens northward, and corresponds generally to the line of deep soundings. The eastern boundary is not well defined; as on the west the cold wall forms a very sharp line of demarcation, and as, a little northward, cold water lies in mass below the stream, it flows as a river in a channel bounded by water of lower temperature. Laughton has pointed out that its surface is like that of a river convex; but the friction being greatest along the cold wall and least on the eastern side, the summit of the convexity is close to the western side, just as at the bend of a river it is close to the bank against which it is thrown. It is this easterly slope of its surface which prevents wreck from the West Indies from being stranded on the American coast; a fact otherwise inexplicable since surface movements in various directions have been recorded. The temperature of the stream is not uniform even in the early part of its course, for, in sections at right angles to its flow, the American Coast Survey has found alternate bands with a difference of 1° to 2°C.; thus passing seaward from the cold wall, the maximum temperature of 27·8°C. prevails for 60 miles, for the next 30 miles the temperature is 25·5°C.; the high temperature, 27·4°C. occupies the next 170 miles, and is succeeded by 25·5°C., then 27·4°C. The cooler bands correspond to the position of deeper channels in the sea bed, parallel to the coast, and containing thicker masses of the polar current.

87. Movements beyond 45° N. Lat.: their Cause.—Beyond 45° N. lat., the course of the stream has been made subject of dispute. According to the generally received opinion, it spreads over the Atlantic towards the European shores; a portion is deflected to the Gulf of Guinea, and rejoins the equatorial drift; the rest is traceable northwards between Iceland and Norway to Spitzbergen, on whose shores West Indian fruits have been found, and it was even thought to reach the coast of Siberia. But while the presence of warmer water to the far north is admitted, its impulse by the Gulf Stream has been denied. That current has been declared to cease at about 45° N. lat., and the diffusion of warmer water, even though its speed between Scandinavia and Iceland has been calculated by Irminger at 1½ to 2½ miles a day, has been attributed to the influence of the anti-trades, or to the contraction of the polar seas by cold, and the expansion of the equatorial by heat, a slope thus being created down which the water flows. A good deal of discussion has arisen from the claim put forward for one or other of these influences as the exclusive cause of motion, and our imperfect knowledge of the laws which regulate the movements of great masses of water, has necessitated the introduction into the controversy of a large amount of hypothesis. It seems, however, that gravitation alone does not supply the necessary force, any more than do the westerly winds, whose steadiness, however, is likely to accelerate a current which "holds its way" in a mass, having started with a high velocity. The Lightning and Porcupine Expeditions showed that the N. Atlantic has an upper stratum of warmer water overlying a deeper colder portion, and that this upper stratum has a tolerably uniform thickness of 800 fathoms between the Bay of Biscay and the Hebrides. But the warm water in certain localities reaches the bottom, the colder water being entirely excluded, and thus there may be in close proximity two columns of water of very unlike temperatures at corresponding depths. The relations of temperature to depth in the warm and cold areas thus discovered, are shown in the following columns, from which it appears that the temperature of 5°C. is in the one case at less than 200 fathoms from the surface, in the other at 567 fathoms deeper.

Lat. 61° 21′ N. Lon. 3° 44′ W.		Lat. 59° 35′ N. Lon. 9° 11′ W.	
Temperature.	Depth.	Temperature.	Depth.
10°C.	0 fathoms	11°C.	0 fathoms.
5°	180 ,,	8°	350 ,,
0°	320 ,,	6°	600 ,,
−1°	500 ,,	5·2°	767 ,,
−1·2°	640 ,,		

The existence of this relation is more striking when the line of soundings and temperatures in the Faroe Channel, *i.e.*, between the Faroe Islands and the Shetlands, is tabulated.

Latitude,………	60° 14′	60° 4′	59° 56′	59° 48′	59° 40′	59° 34′
Depth (fathoms),	632	605	363	445	190	155
Surface,……….	11·1°C.	11·4°	11·4°	12°	12·1°	11·4°
Bottom, ………	−0·8°C.	−1·2°	−0·3°	−1°	9·3°	9·5°

The warmer water thus dams up the colder across the southern end of the channel. But this colder portion has 7°C. lower temperature than water at the same depth in the Atlantic, while, on the other hand, it is nearly three degrees colder than the bottom water in the Bay of Biscay at 2435 fathoms. Further, the bottom temperatures off the Norwegian coast are 6·5°C. in depths of 700 fathoms. This unequal thickness of the warmer water is not compatible with a gravitation theory, according to which the cold water would be found always beneath the warm; nor, if convection (*i.e.*, the distribution of heat by the transfer of masses of warm water) took a prominent place, should we expect to find the distinction so marked between adjacent columns of water, a distinction comparable to that of the cold wall near the starting point of the Gulf Stream. It appears, then, that there are two opposite movements, that of the Gulf Stream holding its course and tending to the north-east, and that of Arctic current tending more slowly southward. But this is a very slow movement, and the water lagging behind the earth in its rotation acquires a south-westerly direction, passing towards the American side, though a small portion moves *towards* Scotland, becoming mixed with the warmer water.

The Stream enters a *cul-de-sac* in the north Atlantic and is dammed up; hence its comparative depth where, unless it were driven north by some impulse from behind, it would thin away; hence, too, partly because there is a reflux from the point of obstruction, partly because of the eastward tendency of the mass, the waters of the Scandinavian coast have a higher temperature at all depths than is due to their latitude. While the course of the Arctic indraught to the south-west is clear, the source of the cold water in the Bay of Biscay is more doubtful. The Arctic fauna is carried down in the cold area into comparatively low latitudes; but as that area and the Bay of Biscay are separated by water never lower than 6° C., it is probable that the low bottom temperature of the latter represents a cold Antarctic indraught, a view supported by the continuously low temperatures already noted as crossing the equator. While the indraught from the north is usually very slow, it acquires some velocity in two places, namely, in the deep channels along the east coasts of Iceland, and Greenland.

88. Labrador Current.—The Arctic indraught is joined by another, the Labrador stream, which forms the bulk of the water that skirts the American shore, maintains its lower temperature at the cold wall and enters the Mexican Gulf itself beneath the outflowing stream. On this last point counter statements have been made; it is at all events certain, that the cold water passes underneath the warm and rises towards the surface on the eastern side of the stream, so that the influence of the northern waters is felt in the equatorial area. The velocity of the coast current is small, its maximum is 15 miles a day, and south of Cape Hatteras it is slower, its movement being sometimes reversed, probably in consequence of the friction of the Gulf Stream tearing off a part of the water, as the air column in the Odorator has its top torn off by the horizontal current.

89. Rennel's Current.—The somewhat variable Rennel's current is a drift which, coinciding with the eastward movement of the Gulf Stream, has its force and extent modified by the strength and continuance of the westerly winds. The drift impinging on Cape Finisterre is turned northward, and finally is lost in the ocean, whither it is diverted westwards from Ushant. The importance of this current lies in its power to drive ships as far out of their reckoning as the Scilly Isles, when seeking to make the English Channel.

90. Mediterranean Currents.—The Gibraltar current, which at the Straits attains a velocity of even as much as 80 miles a day, resembles the Gulf Stream itself, and the stream through Dover's Straits, in that it is a body of water whose velocity gradually increases towards the apex of the funnel formed by the convergent trends of the Spanish and African coasts. Within the Mediterranean the velocity diminishes, but a current may be detected along the south shores turning northwards along the Asiatic coast, the drift eastwards being maintained by westerly and north-westerly winds. The existence of a steady under current of outflow through the Straits is a matter of dispute, Dr. Carpenter affirming its constancy, while others regard his observations as too few to warrant that conclusion. It must further be added that the Gibraltar current has itself been regarded as mainly due to the conversion of the tidal movement into a wave of translation, thus explaining the frequent reversal of its direction, and rendering unnecessary the complicated hypotheses as to the replacement of water lost by evaporation. The existence of an inward current at 20 fathoms depth, from the Ægean into the Black Sea, seems to be established by the Hydrographical Survey, the surface current setting outwards at a rate of about 25 miles daily. Carpenter assigns the under current to the effort to restore equilibrium in the Black Sea, by pouring in salt water of higher specific gravity to replace what flows out at the surface. Spratt asserts that there is no movement at 20 fathoms, and that the surface current is reversed in winter when the rivers are low, the removal of salt water thus taking place at one season, and being compensated at another.

91. Baltic Currents.—A surface outflow and an inflowing under current have been affirmed on theoretical grounds to exist, and Meyer of Kiel gives evidence in favour of their existence. There is a great influx of fresh water into the Baltic from the adjacent land, and Carpenter assigns to this an elevation of the surface, and consequent flow-off, the under current restoring the equilibrium between the waters on either side of the strait. Both the explanation and the existence of these Baltic movements have been doubted, and in the meantime it can only be said that the agency, appealed to by Carpenter, may operate along with the impulse of the Gulf Stream as it flows back from the Arctic Sea in which its progress has been arrested, but that it cannot yet be regarded as sufficient to produce all the phenomena, even supposing the movements to be accurately known.

92. N. African Current.—The N. African current is a large body of water which clings to the coast, and, as the Guinea current, rejoins the equatorial current.

93. Sargasso Sea.—The drifts and streams now mentioned leave in the centre of the ocean an area of comparatively little movement, in which, as in a dead water, a vast amount of Sargasso (Sargaço) or gulf weed, accumulates and forms a mass sometimes 60 fathoms deep. The locality and limits of this sea are variable, its average position being between 20° and 30° N. lat., and between 30° and 60° lon. W.

94. S. Atlantic Basin.—The Brazilian current, already mentioned, has an average speed of 15 miles, and, after receiving the Plate river, merges in the connecting current, which is a portion of the great eastward drift in the Antarctic Ocean. The cold water from the south enters the S. Atlantic Ocean more centrally than the corresponding supply to the N. Atlantic; the summer isothermal line of (60°F.) 15·5°C., reaching to 18° lat. S., while that of the northern basin does not descend below 35° N. lat. In our ignorance of Antarctic geography, it is impossible to say what may be the influences which give to the easterly drift its powerful northwards tendency in the Atlantic. But the southers which blow at Cape Horn, and the icebergs which travel northward, suggest the existence of currents which help to carry the eastward drift to the north.

95. Antarctic Drift.—The southern circumpolar sea may be regarded, as has been mentioned (Art. 65), as a single zonular ocean, of which the Antarctic drift is the principal movement, and when we find that the current which sets into the South Atlantic round Cape Horn is derived exclusively from this Antarctic drift, we may say that the Atlantic basin *derives no appreciable* contribution from the Pacific area; but the connection of the Atlantic with the Indian Ocean, and of the latter again with the Pacific, is more direct and obvious, none of the continental lands projecting into the Southern Ocean to the same extent as does the southern extremity of South America. The arch which the southern connecting current describes across the Atlantic, extends as has been said to about 15° south latitude, and returns towards the Cape of Good Hope, passing along the coast round the Cape into the Indian Ocean. One portion of it, however, turns to the north, and runs parallel with, but in the opposite direction to, the Guinea current, forming, in fact, the first part of the equatorial drift, and having a temperature nearly 7° C. lower than that of the Guinea current. The equatorial current has thus a northern and a southern source of supply, which converge westwards, but leave to the east a triangular space which is closed by the Guinea current. In this space, which corresponds in position to the Doldrums, a counter current sets eastwards with considerable velocity. A space is again circumscribed by the south, connecting the equatorial and the Brazil currents, which has neither the extent, comparative fixity, nor sea weed of the Sargasso area, of which it is the southern counterpart.

This drift, in the main eastward, though its direction varies a few points at various places, has a steadier set the farther north it is followed into more temperate regions. The variations southwards are due possibly to irregularities of the Antarctic coast line, whose form is, however, unknown; and, without doubt, the large quantity of fresh water pouring from the great ice cap during summer must have considerable influence.

96. **Antarctic Drift: Pacific**—This great eastward movement, which has an average speed of 10 to 15 miles a day, is affected by the two land pyramids, South America and Australia. Near Cape Horn it divides, one portion entering the South Atlantic Basin, the other, which may in strictness be regarded as a backwater, running up the western side of the continent. This mass has a very extensive surface, the landward portion being known as Humboldt's, or the Peruvian Cold Current, the western portion as Mentor's. The main body of water runs northward, and is turned

towards the west partly by the projection of the Peruvian coast, partly by contact with the dead water which fills the indented coast line of Central America. Thus the southern source of the Pacific equatorial current is, as in the Atlantic, derived from the colder waters of the Antarctic regions. The northern source is derived from the current which follows the coast of North America, and whose westward deflection, aided by the north-east trades, is primarily determined by contact with the tropical dead water. Between the two roots a space is left in which an equatorial counter current sets eastward, and, as in the Atlantic, is in effect a backwater formed by the two.

97. **Pacific Equatorial Drift.**—The equatorial current illustrates the homomorphism of Eastern Asia and Eastern America. To the north of Torres Straits it is deflected northwards, and following the curve of the land to the outside of the Philippine Islands, runs up as the Japanese coast current as far as Behring's Straits. This body of water is the counter part of the Gulf Stream, being like it, warm, blue, and salt; but its velocity is less, since it is not accelerated by being confined within a basin like the Mexican Gulf. Part of the stream passes through Behring's Straits, and, while the major part continues eastwards, carrying warm water along the north shores of America till it finally merges, in Davis Straits, in the Arctic currents of the Atlantic, a small portion turns to the west, and may maintain open channels in the ice, but its influence must be small since, as has been well pointed out, it affects only feebly the freezing of the water in Norton's Sound. The second branch of the current crosses to the American shores, and, aided by the north and north-west winds, follows the Californian coast to complete the circle by joining the equatorial current. Of the great area which lies within this circle little is known; there is no positive information as to whether the Sargasso Sea has an equivalent in it.

98. **Australian Currents.**—As the Australian continent is a diminished representative of the South American, African, and Indian land pyramids, the currents on its shores correspond to those of the African and American apices, especially to the former, which likewise projects into the Antarctic

drift, and has a land mass to the eastward. The drift, rushing past the south shores of Australia with a velocity increased by the steady westerly and south-westerly winds of high latitudes, turns northward between Australia and New Zealand, and at times has a speed of 100 miles a day. It runs in a trough between two southward currents, the principal one being that which skirts the south-east coast of Australia with a considerable velocity, the number and magnitude of the return currents or backwaters along the coast being in proportion to its speed, friction having the greater influence, according to the cricketing rule which Laughton quotes very happily, "a slow ball must be played, it will not play itself." The meaning of this rule, which is well worth bearing in mind, is that, whereas holding the bat still at the proper angle will send a swift ball where it may be desired, a slow ball striking on a steady bat will be stopped; to send it, therefore, in any direction, it must be struck. The side currents in the Australian channel are portions of the equatorial drift which have been deflected southwards by the Polynesian Islands, the speed being increased by passing through the narrow straits between them.

99. Currents of Indian Ocean.—The currents in the Indian Ocean illustrate the important influence of dominant winds on the movements of the ocean. The Monsoons of the northern part of the ocean are reflected in the changing direction of the currents on either side of the Indian Peninsula. The south-east trades maintain a westward movement whose limits shift to north and south with the trades, and which corresponds to the equatorial currents in other seas. This current turns to the south at Madagascar, and reaches the African coast as a rapid stream, a small part of which enters the Atlantic, while the great bulk turns eastwards with the Antarctic drift, and again runs northward along the Australian coast, thus completing a circle and circumscribing a deadwater. In winter the waters of the Mozambique Channel are partly drawn out in front, partly driven from behind by the northerly wind, and join the southward stream with a high velocity. But when the wind blows up the channel to the north, and when at the same time the westerly drift reaches to the equator, and is turned southwards as it approaches Africa, the waters of the channel are drawn in two directions, and the currents in it become uncertain. Laughton suggests that the constant southward movement should be called the Natal current, and that Mozambique current should be restricted to the variable movements in the channel which he has shown have been mistaken for a part of the Natal stream.

100. Red Sea.—The waters of the Red Sea move southwards during summer, and join the eastward current in the Arabian Sea, the outflow being (from June to September) at the rate of 40 miles a day. This outflow occurs at the period when, if excess of heat alone determines movement, an inflow should take place. It is during winter that an inward current sets through the Straits of Babel Mandeb, though probably an indraught passes the Straits during most of the year to replace the excessive loss by evaporation.

CHAPTER IV.

THE FUNCTIONS OF WATER.

The water which is removed by evaporation from the ocean is restored to it directly by precipitation from the clouds, and indirectly by the streams which drain the land. But the water surface thus distributed over the land is itself an area of evaporation, and even the ice and snow of polar regions contribute to the atmospheric moisture. Thus the rainfall on land is derived from the land as well as from the sea; that on the sea is in turn a direct or an indirect restoration of water that has been withdrawn from it. But whereas the rain reaches the earth comparatively pure, or at least bringing down matters which have been raised for a short distance above the earth, the river enters the sea heavily laden. It carries matters soluble and insoluble; chemically dissolved and mechanically suspended; and these are distributed by the movements of the ocean. The insoluble portions are laid down under the influence of gravitation; the soluble are so diffused that the waters of the ocean have an average composition everywhere except close to land. It is most important to the geographer to know the power of rivers as agents of waste—to learn what they actually do. From exact data man can calculate his power to avert the disasters wrought by an element as remorseless as fire; or, if that is beyond his power, to mitigate the effects of the calamity. He can guess approximately the time required to effect certain changes on the earth, and thence foretell the completion of other changes, whether these be the wearing away of a continent to the level of the sea, or the final closure of a river presently navigable. The annals of the human race are not written in sand, but part of the record is built in the alluvium of the Nile; and history repays the obligation by fixing with certainty the dates at which the action of rivers closed the prosperity of a region by destroying its ports, and thus furnishing a standard by which to measure the rate of geological change.

The detailed anatomy of rivers, above and below ground, is essential to our appreciation of the history of nations. Whether rivers are navigable or not; whether they open into seas, of which the currents or the prevailing winds offered obstacles not easily overcome by uncivilized man; whether the underground streams reach the surface as potable springs, or remain below ground till man has acquired the knowledge, the skill, and the means to render them available; on that depends the early or late development of the inhabitants of a country. These determine whether a country shall contribute to human progress, or remain unprofitable till that remote time when men, crowded out of the more productive regions, shall be forced to enter into a struggle with unfavourable conditions.

SECTION I.—RIVERS.

Complexity of Rivers—Drainage Area or Watershed, Waterparting — Quaquaversal Watershed, how formed — Rivers cutting across Mountain Chains—Antiquity of British River Valleys—Shifting of River Courses, and Return to the Original Channel—Permanent Changes of Course due to Movements of Elevation—Direction of Rivers altered by Disturbance of the Earth's Crust —Sources of Rivers—Motions and Form of Stream—Floods: Flood Waves—Speed of Rivers—Transporting Power of Water —Sediments in Rivers—Drainage Systems: their Relations to Oceans—Divisions of a River Course—Waterfalls, Rapids—Drainage Areas—North American Rivers: Southern Slope, Mississippi, Arkansas, Missouri, Red River, Ohio; Eastern Slope, Potomac, Susquehanna, Hudson; Northern Slope, Great Fish River, Mackenzie River—Mexican Gulf—South American Rivers —Eastern Tributaries of N. Atlantic; Northern Slopes of Europe; Asiatic Continent—Rivers of West Coasts of Europe—Rivers of British Islands—Rivers entering Baltic and Mediterranean—East and South Shores of Mediterranean: the Nile and its Tributaries—West Coast of Africa: Senegal, Niger, Congo, Orange River—Indian Ocean: Rivers of Eastern Africa; of Arabia and Persia; Rivers of *Himalayan Origin*—Southern India: homomorphic with Africa—Table of Relative Geological Importance of Principal Rivers—Pacific Basin: Western Shores; Hoang-Ho, Yang-tze-Kiang, Amoor, Song Ha, Camboja: Eastern Shores; Colorado, South America: Australia: Murray River, Macquarrie, Darling: New Zealand—Rivers of Inland Drainage: Africa, Central Asia, Aralo-Caspian Area.

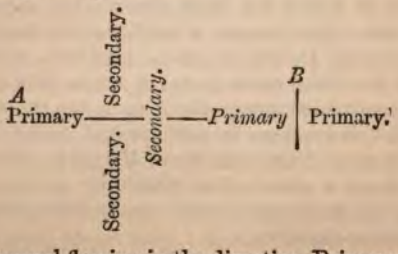
101. A River is a Complex Water Channel.—The simplest type of a river may be illustrated by a stream which flows down the muddy banks of a tidal estuary as the tide ebbs. The plane of marine denudation, and the straight course of the primary channel down the gentle slope are well illustrated, while as the water sinks the secondary channels become conspicuous, until at last we have on a small scale a complex drainage system formed by the combination of primary and secondary channels in the way already described (Art. 43).

A number of originally distinct river systems may combine into one; as, for example, in the North American continent, where the Mississippi receives the drainage of higher grounds to the east, north, and west, the drainage system corresponding to that of at least three primarily distinct areas. The most important rivers are those which flow parallel to the longitudinal axis of a country; and these, as has been already explained, occupy the valleys formed by the junction of the secondary streams which cut back the ridges that at first separated them, and thus came to form continuous grooves. To follow the course of the Mississippi, the first part of the Missouri consists of longitudinal and transverse streams, while between the forty-third and thirty-ninth degrees of latitude the longitudinal stream is the principal. From about the last mentioned point a transverse channel pours the waters of the Missouri into a common stream with the Mississippi. Lower down, the Ohio, chiefly a longitudinal stream, enters the same valley, while the Arkansas and Red Rivers enter directly as transverse channels into the lower part of the Mississippi. The Mississippi, below the mouth of the Red River, flows through a delta laid down in a deep estuary, which runs into the mainland, and which, if prolonged, would join the lake region, and help to isolate an eastern from a western mass of land. If this valley were submerged, the Mississippi system would be broken up into a large number of distinct water systems. But if the processes by which the Mississippi is at present building out its delta into the Mexican Gulf be continued sufficiently long, we should have the complexity of the river system increased, and the same alternation of transverse and longitudinal streams would recur. The Amazon offers an exactly similar picture.

102. Drainage Area or Watershed, Waterparting.—By the term drainage area is meant all that surface of country the slopes of which direct the waters flowing from them towards a common point; and the separation of drainage areas is the waterparting, a term more strictly correct than watershed, which is commonly employed. It would avoid confusion were versant employed for the surface which intervenes between the waterparting and the watercourse.

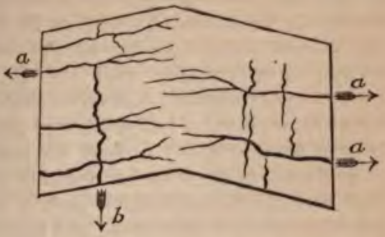
103. Quaquaversal Watershed, how Formed.—It is not necessary that the summit of the waterparting should be at any great elevation; in fact we frequently find the boundary between two contiguous drainage areas formed by a feature of the ground so slight as to be a scarcely appreciable disturbance of the level of the plain; and from what has been already said regarding the mode in which two adjacent valleys open into each other by wearing down the higher ground separating the head waters of two streams, it is obvious that by the removal of the whole of such an intervening ridge two valleys may be laid into each other, and the last trace of a waterparting effaced. Examples of this are found in several parts of the world; and a notable instance is met with in South America, where the Casiquiare connects the Orinoco and Rio Negro. These quaquaversal watersheds, the existence of which has been denied, but erroneously so, are of frequent occurrence on a small scale in most countries. One such is found in the centre of Scotland, where a small plain in the Pentland chain forms a connection between two streams, one of which enters the Tweed, the other the Clyde; and through this common feeding-ground salmon have passed from the one side of the country to the other, their ascent by the Clyde being a physical impossibility on account of the Falls, while the transport of the ova by birds has an exceedingly slender probability.

104. Rivers cutting across Mountain Chains.—One step more in the lowering of a watershed may carry the whole of a river into another channel, and it is to this extreme result of atmospheric denudation that we owe the intersection of mountain chains by streams that flow in one direction. Thus in Derbyshire, and other parts of central England, streams which take their origin in the centre of a hill range, after travelling across the low grounds for some distance, pass right through another mass of high ground in their progress towards the sea. There are only two possible explanations of such an occurrence, the one being that the original plain of marine denudation was traversed by a watercourse in the direction of the existing stream: that later denudation carved out a channel at right angles to it, and that this channel was worn down so rapidly as to fall below the level of the primary valley, whose waters were diverted into this new course. The later valley helped to isolate a mass of the primitive plain, and leave it as a hill of circumdenudation, the drainage of which, falling into the primitive rivercourse, went in opposite directions, and thus created a waterparting in the middle of what had been a continuous channel, so that the relations of the primary and secondary valleys became reversed. By the slow lowering of this waterparting the continuity of the valley might be restored, and the waters of the secondary valley again carried down in the direction they had originally followed. Another explanation is that the valleys which isolate the hill masses are the primary channels, and that those which intersect the hills are the secondary streams, whose more rapid denudation has enabled them to divert the waters of the primary river.



A river channel flowing in the direction Primary—*Primary*

—Primary, and traversing a valley between the high grounds A, in which it originates, and B, through which it flows, may have its direction thus fixed: 1*st*, Because both A and B were parts of the original marine denudation from which the primary stream flowed, and continued to flow, while tributaries to right and left, marked secondary, deepened their channels. 2*nd*, But A and B may have furnished tributaries to a primitive stream in the position marked *secondary*, and by a lowering process such as formed the channel *b* (adjoining figure), the two channels on either side of the waterparting B may have been laid into each other, and so carried off the whole waters in a direction at right angles to their original direction. In these two cases Primary and Secondary are reversed. A third case is when the secondary channels have become one, as in the figures Arts. 43 and 104, and the Primary stream which traversed the original plain has its upper waters deflected into this new channel: the lower course *Primary*—Primary, now conveying less water, gradually forms two streams in opposite directions from a waterparting in the middle of their once continuous bed at B. The first of these cases is that of the Wye in Derbyshire; the second is that of the Lyne water, which rises in the Pentlands, crosses the low grounds, and enters the Tweed through a gap in the silurians. The third is possibly the relation of some of the N. American rivers, the change being, however, due in part to glacial obstruction or earthquake movements.



Sinuous waterparting: longitudinal valleys formed by wearing down of ridges between the tributaries of *a a*; stream flowing in direction *b*.

105. Antiquity of British River Valleys.—The history of the river valleys of the United Kingdom is complicated by the numerous subsidences and re-elevations which have occurred in that area; but the labours of Ramsay, Jukes, Geikie, and others *have proved* that the river valleys of this country are of very great antiquity. The inspection of the geological map of Scotland shows that patches of old red sandstone are found in the hollows of the Lauder, in the south of Scotland, and far up the estuary of the Tay; that carboniferous strata are met with at Thornhill, in Dumfriesshire; and that the permians lie in the heart of the hills in the valleys of the Annan and the Nith. As these are all sedimentary deposits, it is clear that at the time when they were accumulated a valley existed and had generally the same form as we now see. In fact, the plain of marine denudation as it is seen in the silurian uplands of north and south Scotland, and the reasons which justify the belief that that plain was once covered by the old red sandstone formation, demonstrate the extreme antiquity of Scotland as a mass of dry land, and consequently the extreme antiquity of the first valley grooves which were excavated on its surface. The valleys, therefore, which must have existed before the deposit of the old red sandstone strata, now exist, and many of them are still the leading drainage channels of the country. The history thus unravelled is essentially the same as that of the valley formations in Norway and Sweden. But in Britain the more frequent submergences, or at least the greater depth of more recent depressions, somewhat obscure the details of the original valley systems. Perhaps the most satisfactory proof of the tendency of streams to return to their original channels is furnished by the events subsequent to the glacial period, at the close of which the country was covered by a layer of glacial detritus upwards of 2,000 feet in thickness. But this deposit conformed generally to the principal inequalities of the ground, so that the leading depressions, such as the groove of the Forth and Clyde, the Caledonian Canal, and the Great Glen, must have been indicated at all times. In the smaller streams, however, as in the Clyde, the Tweed, and the Tay, we find that while part of the course is through solid rock, at other points it is cut in masses of glacial detritus. The river has, in fact, returned to its original line; it is still engaged scouring out a channel which was choked up by the glacial detritus, but having failed in some places to resume its original direction from the compactness of the till, it has *found an easier* passage through the stratified rocks (Art. 115).

106. Direction of Rivers Altered by Disturbances of the Earth's Crust.—But while in North Britain this tendency to reversion is thus manifest, in the south of England we find proofs of an entire change in the directions of the rivers, besides that case mentioned in Art. 53. Thus the Weald of Kent represents the delta of a great river, which, flowing from the west, entered the German Ocean probably in conjunction with some large continental stream, perhaps the Rhine, the joint estuary being far to the north of the present coast lines. These remains of former land surfaces date from the period of the chalk, the dry land at that time forming a continental mass which stretched westwards towards the Atlantic, and was continuous with elevated ground in the south of Europe. Thus the evidence of change in the trend, as well as in the position of the former continental areas, is very complete.

107 Sources of Rivers.—The gathering grounds of rivers are necessarily those portions of the country which are above the level of the stream; or, to put it more plainly, water could not scoop out a channel for itself unless it descended a slope, and the excavating power of a stream is therefore proportional to its velocity, that is, to the inclination of its bed. The source of a stream is fan-shaped, all the rills converge to the lowest point, and their junction will be nearer to or farther from the waterparting according as the versant slopes rapidly or gently. It is impossible to fix any one rill as *the* source of a river; and this is especially the case where the drainage of two or three distinct tracts unites in one great stream, as the Mississippi and Amazon. Atmospheric moisture is the ultimate source of all streams, whether it contributes to them directly as rainfall, less directly by the melting of ice and snow, or still more indirectly by means of the springs which return to the surface the water that has soaked into the ground at higher levels, and has sunk to various depths.

108. Motions and Form of Stream.—In no case is the volume of water in a stream equal throughout its length and at all times. Seasonal differences are of regular recurrence, but the variations may be very frequent in glacier regions, where the cold during the night diminishes the streams which the heat of the day again enlarges; or they may be at long intervals, as in sub-tropical countries, where a drought may last for years in place of a season. The size and volume of a stream are determined by the rainfall. It may enlarge and diminish gradually, or the enlargement and diminution may take place suddenly, constituting what is known as a flood. The surface of a stream is not flat: the water moves more rapidly in the centre than at those points where it is in contact with its channel. The foam lines are seen to be curved, the convexity of the curves pointing down stream; and the curves are more or less rapid in proportion to the speed of the river or the narrowness of its channel. While, therefore, friction against the banks retards the marginal water, the bottom water is likewise held back, so that a descending mass of water presents a curve from side to side, and from the bottom of the stream to the centre of the curve. A river, therefore, descends its slope in the form of a succession of shells of water. When its volume increases, the difference is first felt in the centre of the stream, which rises more than friction allows the sides to rise, just as the mercury in the barometer, when tending upwards, has its surface convex, and friction gives to the river and to the mercury a concave surface when the tendency is downwards. Objects thrown into the centre of a rising stream travel towards the margin; as the stream sinks they return towards the centre. At the bend of a river floating bodies are carried with the stream against the bank, but their speed increases as they approach it, and they are not thrown off at an angle (unless they are heavy), but rush down the curved surface of the water, and rise to the surface lower down and nearer the centre of the stream. A backwater or reverse current along the sides of a river is found below an obstruction, such as a projecting bit of the bank: the water in the lee of the obstacle would be still, but the stream skirting it drags away its margin, and thus, by friction, creates a movement, the water moving up along the bank to replace that which is carried away by the downward flow. If the projection is slight, there is only one backwater. If the bay on its up side is wide, a backwater is directly formed by a portion of the stream sweeping into and round the bay. Thus the St. Roque current strikes on the Mosquito coast in the Caribbean Sea, and forms a backwater, while the peninsula of Yucatan gives rise to another in the Bay of Vera Cruz.

109. Floods—Flood-Waves.—When a quantity of water is suddenly poured into a stream it rises, but unless the supply is kept up it immediately sinks. The suddenly formed elevation travels forward, but as it travels, the convexity gradually flattens, till at last the excess of water is evenly distributed. The form of the flood-wave is that of the wind-wave on the sea—a long slope up stream, and a shorter slope down stream. If it enters a lake, its progress is checked, partly because it subsides by spreading, partly because its way is stopped by impinging on the still water. The wave which begins at the outflow of the lake is less violent, because it does not start with any impetus. The same regulative influence is exerted even more strongly when the stream passes through a swamp, or pours part of its excess of water on the adjacent ground, or escapes into sidings. These are sometimes natural; but their artificial preparation is recommended where the ground which it is proposed to flood is unproductive, or of less value than localities farther down, which require protection from the worst fury of the waters. The most mischievous floods are those which occur where rivers flow from temperate to arctic regions, like the Mackenzie River of North America, and those of Siberia, or where they descend from the snow line to warm plains. In the former case, the flood wave descends at the season when the lower waters are frozen, and must therefore spread over the adjacent region; in the latter, the rapid summer melting pours great bodies of water suddenly on the low grounds.

110. Speed of Rivers.—The velocity of a stream is in proportion to the inclination of its bed; but, under exceptional circumstances, as when it is checked by having to pass through a narrow gorge, it is in proportion to the slope of its surface, for there is thus created a constant and fixed flood-wave. The average slope of a river bed is about 6 inches in the mile, or 1 in 880, but in particular streams this estimate may be too much or too little. Even in the same stream the measurements vary. Thus the Missouri, from its source to its junction with the Mississippi, measures 2,908 miles, and it descends 6,800 feet; its average slope therefore is 28 inches per mile. In the first 264 miles it has a slope of 16 inches per mile; in the next 750 miles its slope is 10·56 inches per mile; for 648 miles its slope is 13·20 inches per mile; for 404, 12·12; for 358 miles, 10·32; for 484 miles, 9·24. The first 1,330 miles of the Mississippi slope at 11·74 inches; between Cairo and the mouth, 1,088 miles, the inclination is 6·94 inches per mile; but of this, the last portion, 855 miles in length, has a slope of only 4·82 inches per mile; and the lower half of this portion gives the following: mouth to 100 miles, 1·8 inch per mile; 100 to 200, 2 inches; 200 to 300, 2·30 inches; 300 to 400, 2·57 inches. The slope of the Rhine is 1 in 414, but the lower 225 miles show only 1 in 2,324, the upper 375 descend at the rate of 1 in 609. The velocity is, of course, least in the lower portions of a stream, where the course is for the most part sinuous and the slope of the gentlest, as in the Mississippi, where it is 1 in 1,100; the Seine, 1 in 5,200. The middle course of the Rhine flows, it is estimated, at 3 miles an hour, the lower portion of the Mississippi at 2¼ miles an hour when the river is at mean height; but these calculations are somewhat uncertain from want of agreement as to the method of observation, and very unequal care in conducting the experiments.

111. Abrading and Transporting Power of Rivers.—The quantity of material removed by a stream is usually in proportion to its volume and speed, but not always. Thus, Livingstone forded rivers in which there was more sand than water, and the freshets of some mountain torrents carry down débris out of all proportion even to the flood size of the stream; but in the latter case the rapid slope of the bed enables a small body of water to set a very large mass of solid material in motion, and the transporting power of the torrent is apt to be exaggerated. Much depends on the form even more than on the weight of fragments—a rounded mass travelling more easily than a flat one, a smooth fragment more easily than an angular one. In comparing the transporting power of different streams this element is frequently overlooked. Sir Charles Lyell gives many instances of the enormous power of water in rapid motion, the flood of the Dee carrying blocks of more than a hundredweight up slopes of 1 in 8 or 10. The flood of Bagnes, occasioned by the giving way of an ice barrier, which had converted part of the valley into a lake, started with a speed of 22 miles an hour, which diminished to 4 miles; a journey of 45 miles being accomplished by this flood wave in 6 hours. The power of a river is usually stated as follows:—Velocity 900 ft. per hour tears up fine clay; 1,800 ft. carries fine sand; 3,600 ft., fine gravel; 2 miles an hour, pebbles as large as a hen's egg. It is therefore in proportion to the velocity and to the materials it hurries along with it. Mr. Login believes that when a river has the proper load of sediment for its velocity it looses abrading power.

112. Sediments in Rivers.—But these striking cases are unimportant geographically in comparison with what is going on daily in every river, solid matter travelling seaward in quantities which are not appreciated till they are reduced to cubic dimensions and compared with familiar objects. Professor Geikie and Mr. Croll have devoted much labour to the investigation of the solid contents of streams, desiring to calculate thence the thickness of the layer annually removed from the drainage bed. Thus, Lyell calculates that the total quantity of suspended sediments in the Ganges, 6,368,077,440 cubic feet annually, could be removed by 2,000 Indiamen, each of 1,400 tons, starting every day of the year. Humphreys and Abbot calculated that the sediments carried annually by the Mississippi into the Gulf of Mexico, 750,000,000 cubic feet, would cover a square mile to the depth of 268 feet. Now, the Ganges drains an area of 432,480 square miles, and the sediments above mentioned represent a lowering of the surface of that area by $\frac{1}{2358}$ths of a foot yearly, or 1 foot in 2,358 years, the chemically dissolved matters not being included in this estimate. The importance of this latter kind of waste may be inferred from the fact that, whereas the Clyde is estimated to remove a foot in 6,658 years from a basin of 1,580 square miles, the Thames, which drains an area three times larger, and discharges more than twice the volume of water, would require 10,144 years to do the same work, if its actions were tested only by the solid matter it carries in suspension. But the Thames drains a chalk area; the Clyde has comparatively little soluble strata to deal with; hence the work done by the latter is exaggerated in comparison with that done by the former, if we omit the chemical action of the former. The details of this inquiry are to be found in Croll's papers in the *Philosophical Magazine*, and in Geikie's *Essay*, which forms Chapter XXV. of *Jukes's Manual of Geology*. The general conclusions in that chapter are that, calculating from the sediments carried into the sea by rivers, the dry land loses a vertical foot in 6,000 years. But this loss is unequal on the high and low grounds, the valleys losing 5 feet in that time, while the more level grounds lose $\frac{5}{9}$ths of a foot; or the table-lands lose $\frac{1}{12}$th of an inch in 75 years, while the valleys part with the same amount in $8\frac{1}{2}$ years. Some uncertainty exists as to the averages relied on, some districts losing more than others in consequence of the less coherence of their materials. The sediments of rivers such as the Mississippi are derived from areas under very unlike climatal conditions, and an average of the whole does not necessarily give the average of each. Changes in climatal conditions may accelerate or suspend the rate of waste; and the majority of the rivers on which calculations are based drain regions in which the hand of man has greatly modified the processes of nature. But the method of research has already brought out many unlooked-for results, and it will, when observations are multiplied, bring us nearer to a reliable standard for the calculation of geological time.

113. Drainage Systems: their Relations to Oceans.—It is most convenient to reverse the natural method of the formation of a stream, and, commencing at the point at which a river enters the sea, to classify all such streams into systems which will thus give some idea of the amount contributed by various masses of dry land to the adjacent oceans. The North Atlantic basin receives the drainage of Europe and of America, but to this must be added the vast quantities of water which pour from the Siberian rivers into the Arctic Ocean, and thence into the North Atlantic, forming part of the cold area in that basin. The contribution from the extreme part of the North American continent is very much larger than at first sight appears, since nearly the whole of the Arctic waters enter the North Atlantic. The Gulf of Mexico must also be regarded as a tributary of the North Atlantic, and the waters of the Amazon and Orinoco are also carried into the Caribbean Sea, and become a part of the

Gulf Stream. Viewed in this manner, the whole West Coast of Africa likewise contributes to the North Atlantic waters; the River La Plata on the other hand passing southward to join the southern connecting current. The principal navigable rivers of the world are those associated with the Atlantic basin, but large as their area may be, they nevertheless do not represent the whole of the drainage, since a vastly greater quantity of water is contained in the small streams which descend to the coast line without uniting into large channels.

114. Divisions of a River Course.—Stream courses have been divided into various sections, artificially characterized as first, second, and third divisions, or upper, middle, and lower. In the case of very large rivers the arrangement is sometimes convenient, because in reality it answers to certain prominent features of the dry land. The upper course of a large river is for the most part highly inclined, and consists of many small branches successively uniting. This is the condition of all streams in recently emerged grounds, or of those streams which flow into arms of the sea that represent submerged valleys. Thus, the Scandinavian rivers flow by tolerably direct courses into the sea, the fiords of that coast line demonstrating the greater extension of the land at a former period. Probably, were the Atlantic basin elevated, we should find a middle and lower course for these streams—courses which they formerly possessed, though we cannot exactly tell at what period. What is known as the middle course of a river is that part of its route in which the inclination of its bed is somewhat less, while the lower course of a river corresponds practically to the alluvial plains. Thus, the Ganges has the first part of its course broken up into many converging streams; the middle part of its course is comparatively short, and lies in the elevated terrace land fringing the Himalayas, while its lowest portion flows through the vast alluvial plains, which have been slowly increasing as the land was gradually elevated. The history of that river is in fact the history of a stream whose estuary ran far into the continent. As the alluvial matters were laid down along its banks, slow submergence maintained the level of the new deposits very little *above that of the* stream. Evidence of this mode of formation of an alluvial plain is found in the soundings of the Indian Ocean, which show that opposite the mouth of the Ganges there is a very deep depression, in which lies a "swatch of no ground," a deep submarine valley, about 15 miles broad and more than 300 fathoms in depth. We have in this hollow an index to the former depth of the Ganges valley, the seaward growth of the alluvium of the river being now checked by the current which travels along the north part of the Bay of Bengal.

115. Waterfalls, Rapids.—In general terms it may be said that the possibility of dividing a stream according to variations in the slope of its bed furnishes an index of its antiquity, though we shall find that the Mississippi furnishes a notable exception to this rule. The continuity of a slope is interrupted either by the entry of a river into a lake or into level ground, or by its falling suddenly in cataracts from higher to lower levels. The origin of many cataracts is somewhat difficult of explanation, but in some of the falls of the St. Louis River of North America it has been ascertained that the present position of the river is not that which it occupied prior to the glacial period, the preglacial bed, choked up with detritus, being still recognizable in the vicinity. The river, which formerly flowed at a considerably lower level, resumed its course in the same general direction, but becoming deflected towards a ridge of rock, the summit of a former escarpment, it was there retarded, dammed back till it overtopped the obstacle and poured across it, gradually deepening the groove. The escarpment was doubtless the slope of the hill looking towards the plain into which the St. Louis flowed at its former lower level The general tendency in such cases would be to lower the height of the fall, till at last a steep sloping river bed should be provided. But in exceptional cases, such as that of the Niagara, the vertical face of the cliff is maintained by a peculiarity in the method of disintegration of the rock. A bed of hard limestone about 90 feet in thickness forms the summit of the cliff, and rests upon a mass of soft shales which are disintegrated by the spray from the base of the fall, crumble readily away, and thus undermine the top bed, letting it fall in blocks which, as is the case with most very compact strata that have been subjected to modification, are of a rectangular form, hence the perpendicular face of the cliff is maintained, and has been maintained during all the time that has elapsed since the falls tumbled over above Queenstown. But the waters of Lake Ontario probably flowed, through a channel now filled up, into the Hudson River, and the selection of the route by Queenstown was due to the piling of rubbish on the south bank of the overflowing lake, so that its waters were driven over a steep slope to the north-east. On a small scale cataracts may arise by a process exactly similar to that by which watersheds are lowered till valleys become united. Thus, in hill regions where a catchment basin occupies the summits, whence slopes descend with different inclinations to the valley, the waters of the catchment basin may be carried over the edge of the steeper face by the wearing down of grooves on its margin, and thus a waterfall may arise in a secondary fashion and be maintained by the progressive eating back of its steep face; or the same result may be attained by the undermining of a cliff so that at last a steep face comes to intercept or open into the bed of some mountain torrent which originally flowed in another direction. The lowering of waterfalls, we repeat, is a normal event; the permanence of their precipitous face is only explicable by special stratigraphical conditions, such as the nearly horizontal hard bed with its crumbling underlying shale at Niagara. A continuous slope may be converted into a waterfall if, by a difference in the hardness of the strata, one part wears away more rapidly than another, the abrupt face once formed tending to perpetuate itself so long as a difference of texture exists. A waterfall may be finally abolished by the diminution of its area of supply, in the same way as we shall find a glacier may be reduced.

The falls of Niagara, with a height of 154 feet on the Canadian side, of 163 feet on the American side, and the Victoria Falls on the Zambesi, with a vertical height of only 100 feet, are among the grandest displays of natural power in the world, a sheet of water 2,400 feet in width being seen at Niagara, while the Zambesi falls over in a mass more than 3,000 feet wide. There are grander cataracts so far as mere height is concerned. The Staubbach descends 1,000 feet, and the Yohamite Falls in California have a single leap of 2,100 feet, the whole descent being 3,100 feet. The Kaieteaur Fall in Essequibo is 742 feet high, and even in June was 370 feet wide, and discharged 500,000 cubic feet per hour—that is, one-sixth part of the volume of the Clyde. An attentive observer will find that the water falls in concentric shells like those of the flowing stream; the marginal waters do not fall at the same moment as the central, and this relation is preserved from top to bottom even of a high fall, if the water drops sheer. But vertical cliffs are not so common as is supposed; they are usually stepped, and when the gradations of the descent give a low angle to the whole, a rapid is produced—that is to say, an incline of water with a velocity which renders it impossible to ascend, and even makes descent precarious, or forms a permanent obstacle to navigation, compelling the traveller to carry his boat and baggage overland by a "portage" to the calmer water above. Another kind of rapid occurs where a permanent shingle bank is developed, or where a constant supply of boulders in the bed of the stream is maintained; the slope of water being in both cases swift, but in one smooth, in the other tumultuous. Between the cascade and the ordinary slope of the river bed, then, there are many intermediate steps which are intelligible only by reference to the past history of the river, or to the character of the rocks of which its bed is composed.

116. Drainage Areas.—The North Atlantic basin receives on the west the drainage of—*a*, Central America and part of Brazil, the Gulf of Mexico being the interposed reservoir; *b*, the coast to the east of the Appalachians; *c*, the great lakes, through the St. Lawrence; *d*, the land surrounding Hudson's Bay; *e*, Temperate and Arctic America, through Davis' Straits. On the east the rivers of the Russian Empire reach the Atlantic by the North Cape; the western European coasts drain directly into the Atlantic, while the drainage of the interior is either direct—as in the case of the Rhine, Seine, Tagus—or indirect, as where Sweden, Russia, and Prussia pour their waters into the Baltic in the north, or where in the south the Mediterranean is the drainage reservoir of an irregular area, the outlying points of which are the Oural Mountains, the Spanish plateau, Equatorial Africa, and the Caucasus. Lastly, the western shores of

Africa contribute to the North Atlantic directly, or by the equatorial drift through the Gulf of Mexico.

The South Atlantic receives the waters of South America to the east of the Andes and to the south of Cape St. Roque.

The basin of the Indian Ocean includes part of the African table-land, the borders of the Red Sea, of the Persian Gulf, and the Arabian Sea, and the Bay of Bengal; the outer limits of the Asiatic area being the Taurus, the Himalayas, and the axis of the Malayan peninsula; while with this basin must be reckoned the western shores of Australia.

The Pacific basin is more simple in its outline, the high grounds near the coast lines limiting the area of supply, except where the Chinese rivers start from the Thibetan plateau.

117. North American Rivers — Southern Slope.—The Mississippi drainage area covers 1,147,000 square miles. Only a small part of the waters of this, the southern slope of the North American continent, enters the Mexican Gulf directly, the lower part of the Mississippi being the common channel of the Mississippi, the Missouri, Arkansas, Red River, Ohio, and each of these in its turn having many large tributaries. The commercial importance of this great system of rivers may be gathered from the fact that the Missouri is navigable for 2,570 miles above its junction with the Mississippi, which is itself navigable for 1,500 miles, so that water communication connects the interior of the continent for 4,000 miles with the ocean.

118. Eastern Slope.—The Potomac and Susquehanna are the chief among the many streams which drain the Alleghanies to the east. The Hudson is now a stream of minor consequence, but was probably in the line of the former drainage of that area whose waters now pass away by the St. Lawrence. This estuary, rather than river, now is the outflow for the great lakes from Lake Superior to Ontario. Newberry has shown that the rocky surface of the watershed or versant of the Mississippi is far below the level of that of Michigan, and that at Bloomington, in Illinois, an old channel has been sunk through to the depth of 230 feet: it is probable, therefore, that the lakes Superior, Michigan, Erie, and Huron drained into the Mississippi, and that the overflow at Niagara was due to the closure of this channel, while the

Lake Ontario, thus largely increased, was, in its turn, driven into the St. Lawrence by the closure of the Hudson valley.

119. Northern Slope.—The Great Fish River and the Mackenzie are the chief streams in this direction, the latter having a length of more than 2,000 miles, and a drainage area of 441,000 square miles. This stream, whose floods have already been mentioned, is the northern drain of a region once continuous with the Gulf of Mexico. The valley of the Mississippi, or more strictly that of the Missouri, was under the waters of the later cretaceous sea, and the Missouri only began to exist in tertiary times, when the cretaceous rocks became uplifted as we now find them to the west of that river. The comparatively slight separation of the south and north slopes is due therefore to inequality of elevation, while the length of the Mackenzie River has been increased by the great amount of detritus carried down by it from a region covered with glacial detritus, just as the Siberian plains have extended northwards.

120. Mexican Gulf.—It is unnecessary to speak of the streams which enter this basin: none of them are very important, save as they illustrate the transverse type of river channels, their course being at right angles to the axis of the respective districts.

121. South America.—The Magdalena, Orinoco, Amazon, drain this continent to the west of the Andes, and as far south as lat. 18°. The two latter rivers are in truth one, since the wearing down of the watershed has connected the Rio Negro and the Orinoco by a cross valley; and the same process will, it is said, ultimately unite the Amazon and the Plate River. In this region, therefore, the erosion of river valleys is well illustrated, and Agassiz has observed that disintegration is especially rapid since the heated surface of the rocks is more readily disintegrated chemically and mechanically by the abundant and warm atmospheric moisture which the decay of a rank vegetation saturates with carbonic acid.

The Amazon, 3,000 miles in length, and tidal for 500 miles, is again, like the Mississippi, the common channel of streams from very different parts of a region covering 2,000,000 square miles, whose flood times do not coincide, and thus the river presents less marked variations in volume than do other streams, the dense vegetation having some share also in this regulative influence. Having at its mouth a breadth of 50 miles, it is still at 500 miles up the country one mile broad; navigable for 2,000 miles, and receiving several large and navigable rivers, it is well fitted to be the carrier of a great trade, when the difficulties of climate have been to some degree obviated by more extended clearing of the forests, and the drainage which that operation will entail.

The Orinoco, 1,560 miles in length, and tidal for 370 miles, drains an area of nearly 400,000 square miles, and is navigable for two-thirds of its length. Its waters, and those of the Amazon, spread seawards with a velocity of about 3 miles an hour, which carries them visibly to a distance of, it is said, nearly 300 miles, their muddy contents rendering them easily recognisable. They are then swept into the Mexican Gulf along with the St. Roque current.

The River Plate, with a drainage area of 900,000 square miles, enters the Atlantic by an estuary of 180 miles in length, the course of the river proper being between 1,700 and 1,800 miles. Its tributaries are also navigable, and are of considerable dimensions—the Salado being over 600 miles, the Paraguay more than 1,000 miles in length. All these South American rivers carry down large quantities of water, the precipitation on the higher grounds being great; and they are heavily laden with sediments, the soft materials of the great plains and terraces being easily disintegrated. The waterparting about 12° S. lat. separates the N.E. from the S.E. slopes, and expands eastwards in the Brazilian Sierras, which consist of metamorphic rocks of palæozoic age. Thus a mass of ancient strata establishes a coast watershed, the streams of which are mostly small, the San Francisco alone having any size; its length is nearly 1,700 miles, and its drainage area about 250,000 square miles. The Plate River drains the eastern slopes of the Andes and the later deposits of the Pampas, and thus forms a part of the area in which the small streams draining the arid high grounds of Patagonia are included.

122. Eastern *Tributaries of* the N. Atlantic—Rivers of

N. Russia.—The rivers which drain the great plateaux on either side of the Oural Mountains, from the North Cape to Behring Straits, have an aspect very similar to the rivers of Arctic America. The whole delta, bounded by a curved line from the North Cape to 52° N. lat., 60° E. long., and thence by Lake Baikal to Behring's Straits, forms topographically, geologically, and by climate a single area, whose waters, pouring northwards, flood the low grounds in winter to a depth of from 30 to 50 feet. The Obi, the Yenisei, and the Lena flow through 20° of latitude, and travel through so much of low ground that the slope from the source of the Lena to the sea is only 1 foot in 5 miles, obviously an exaggeration due to the want of data for discriminating the upper portion from the alluvial flats. The drifting of Siberian timber westwards forms the chief evidence for the Atlantic destination of these waters; but it is probable that some part travels eastwards to join the Pacific indraught.

123. West Coasts of Europe.—The Scandinavian peninsula presents a simple series of transverse streams, of which only the upper courses are above the sea level; the fiords representing their submerged lower valleys. The Elbe travels 550 miles from its Bohemian source, and drains 60,000 square miles of Central Europe, bringing into the sea mineral material suspended and dissolved to the amount of $\frac{1}{7400}$th of its volume. The Rhine, whose remote source is in the Central Alps, has a course of 800 miles, and drains an area of 65,000 square miles. It carries through Holland a burden of sediment amounting to $\frac{1}{100}$th of its volume (Hartsolker); while at Bonn, Bischof found its solid contents to vary between $\frac{1}{4878}$th by weight in flood, and $\frac{1}{57800}$th during a dry season. The Rhine receives the Moselle and the Main, the former passing through a district in which the soft loess holds a prominent place. The Seine has a course of 400 miles, and from source to sea a slope of 1 in 1,628, the inclination being underrated, because its course below Paris is very various. It is navigable for 300 miles. The Loire is navigable for 460 miles of a course of 683 miles; but its shallow, sandy bed renders navigation difficult. The drainage area, 33,000 square miles in extent, is to a large extent among the volcanic rocks of Central France. The Garonne delivers $\frac{1}{100}$th by volume of sediment into the Bay of Biscay, gathered during a course of 360 miles, 260 of which are navigable. The Adour is the last of the important tributaries of the Bay of Biscay, all of which are navigable for some distance inland, thus giving to France a commercial prosperity which makes still more unintelligible to Englishmen the saying that Paris means France. The Douro, Tagus, Guadiana, and Guadalquiver drain Spain and Portugal to the west.

124. British Islands.—No region shows more clearly than do the British Islands the importance of the constant drainage at all points of the coast, as compared with that of the rivers to which the attention of geographers is chiefly directed. The subjoined table, borrowed from Professor Geikie, will give a convenient standard of comparison for other rivers, and a clear idea of the data on which the rate of geological change is calculated:—

	Length.	Drainage Area. Square Miles.	Annual Discharge of Water in Millions of Cubic Feet.	Annual Discharge of Sediment. Cubic Feet.
Thames, ...	200	5,162	54,111	1,865,903
Tay, ...	—	2,500	144,020	49,660,000
Clyde, ...	—	1,580	25,228	8,699,000
Boyne, ...	—	700	94,614	36,622,000
Forth, ...	—	450	15,450	5,328,000
Nith, ...	—	400	—	1 lb. in 32 c. ft. of water.

All the British rivers are tidal. The Thames, navigable for 110 miles above London, below which the estuary stretches for 50 miles, receives tributaries, which are, in fact, a series of canals for the conveyance of agricultural produce. The short course of the British rivers and their comparatively rapid fall, joined with their tidal character, forbid the formation of a delta.

125. Baltic.—The lake region of Sweden, which bears comparison with America north of the latitude of Lake Superior, pours its surplus waters into the Baltic, using that term for the whole body of water which enters the German Ocean by the Skagerrack. The eastern side receives the Neva, Dwina, and Niemen, in addition to a number of smaller streams; while Prussia contributes the Vistula and the Spree. Judging by the number of well known names, the Baltic might be supposed to receive only a small amount of fresh water; yet it is clearly established that, since its communication with the ocean was reduced to what we now see, the shell fish, which yielded to the early inhabitants of Denmark an abundant supply of food, are now stunted in size in consequence of the brackish character of the waters.

126. Mediterranean.—The Spanish coast is drained by a number of streams, of which the Ebro is the best known. The Rhone, which has a course of 500 miles, and drains an area of 25,000 square miles, has a geological importance which may be gathered from the fact that, though its course is one-fifth of that of the Hoang-Ho, it removes, judging by its sediment, one vertical foot from its drainage area of 25,000 square miles in 1,528 years, while the Chinese river removes 1 foot in 1,464 years from an area 21 times larger. On the other hand, the Po, with a course of 340 miles, and a drainage area very little larger (30,000 square miles), does the same work in 729 years. It is unnecessary to enumerate all the streams which enter the Mediterranean on the north, since all of them, with the exception of the Danube, the Dnieper, and the Don, drain only the slopes close to the sea. The Danube drains the great tract of Central Europe which lies to the east of the sources of the Rhine, and between the Carpathians and Balkans. The Dniester, Dnieper, and Don are the leading streams of a tract which is only, so to speak, accidentally separated from the Caspian, the steppe region presenting a singular uniformity of aspect and condition.

127. East and South Shores of Mediterranean.—If the eastern boundary of the valley in which the longitudinal rivers—the Jordan and Nahr el Avy (Orontes), flow respectively southwards and northwards—were prolonged to the 40th parallel of latitude, and carried thence eastwards to the 60th parallel of longitude, the line thus traced would mark off all the Asiatic drainage area which contributes to the Atlantic. The streams are numerous, but none of them are of great size, and the greater number are transverse streams. It follows from what has been said regarding the origin of rivers, that such transverse streams indicate that they are either of recent origin, excavated on emerging land, or (as in Scandinavia and Scotland) that the continuation of their valleys—that is to say, the tracts in which longitudinal valleys have been formed—are submerged. In either case the transverse streams, corresponding to the so-called upper courses of great rivers, are of small importance as regards the commerce of the country. The insignificance of all the North African streams, except the Nile, is due partly to the small size of the coast drainage area, partly to the dryness of the region which, near the heated Sahara, and traversed by southerly winds, has rainfall only in winter; and as this is true also for the Syrian coast, the size of the streams there depends on the elevation and breadth of the high grounds where they take their rise.

128. The Nile, the problems of whose source and floods have not yet been satisfactorily solved, has its most remote sources to the south of the Equator, and then traverses 36 degrees of latitude, and may even have a longer course if Lake Tanganyika should prove to be one of its feeders. Its descent from the level of Victoria N'Yanza is not continuous, being broken by a succession of cataracts, the first of which are the Murchison and the Ripon Falls, on the rivers issuing from the Lakes Albert and Victoria N'Yanza respectively, while the lowest is 555 miles above Cairo, or about 655 miles from the Mediterranean. While the total descent is over 4,000 feet, the inclination of the bed of the river between the first cataract and Cairo is 6·5 inches per mile, and below Cairo is even less. The equatorial sources of the river are still uncertain, but the Abyssinian branches, the Atbara and the Blue Nile (Bahr-el-Azrek, long thought to be *the* source of the river), are well known. The Nile is alone among rivers in having no tributary for the last 1,500 miles of its course. The floods, therefore, which commence in Lower Egypt about the summer solstice, and last for 100 days—the river reaching its lowest state in April or

May—must be due to the rainfall and melting of snow in the equatorial regions.

129. West Coast of Africa.—The same remark holds true for the West Coast of Africa, except in that region which corresponds to the latitudinal band of mountains over which the west wind blows from one side of the continent to the other. The great rivers which pour into the Atlantic, the Senegal and the Niger, or Joliba, are derived from the great mountain masses; and the Zaire, or Congo, which drains the central basin, may yet prove also to derive a part of its water from the same lakes and mountains to which the Nile is traced. In all African explorations a chief difficulty lies in the seasonal changes of rivers and lakes, the wet season filling a channel which had before been dry, and changing first into swamp, and then into a lake, what had been an arid desert. The continued residence necessary to recognize these vicissitudes has not yet been possible for the European traveller; but it is well to bear in mind that conflicting reports regarding any one locality are sometimes reconcilable by reference to this fact, as it has been proved to be in the case of Lake Tchad. The Orange River of South Africa drains the whole breadth of the land from the eastern edge of the plateau to the Atlantic. Its history is not well known; but it contrasts by the length of its course, the continuity of which is interrupted during dry seasons, with the streams which drain the southern extremity of the continent, among which the transverse and longitudinal valleys are beautifully exposed.

130. Indian Ocean: East Coast of Africa.—The Zambesi is the principal stream of this side of the continent; it is the counterpart of the Orange River as the drain of the central plateau, but its importance, geologically speaking, is less than that of the Lufiji, which reaches the coast after traversing a range of mountains two months' journey in breadth. It is not known whether this remarkable course has been formed by the fusion of two streams flowing in opposite directions on either side of the lip of the central basin, or represents a primitive stream whose route was marked out during the emergence of the land. The Zambesi is a striking example of river erosion pure and simple, unaided by atmospheric moisture during large part of its course. The walls of the ravine below the falls described by Livingstone are vertical, like those of Colorado Cañons, and for the same reason that the dry atmosphere has no power of wasting the cliffs, and giving them that sloping form characteristic of the valley walls of temperate regions (Art. 45). The size and permanence of the stream testifies to the abundant water supply at its source, since evaporation during its course does not affect its continuity. Abyssinia is drained chiefly towards the Nile, the streams which descend the eastern slopes being of the same character as that of the African coast lands generally.

The Arabian shores are not sufficiently known to furnish any information regarding the probable annual quantity of water they shed seaward. The Abyssinian and Arabian coasts are identical in type, the characteristic table-lands and valleys of the African being repeated in miniature on the Asiatic side. But the streams in the nullahs are uncertain, and the water is for the most part below the surface. The Tigris and Euphrates, which enter the Persian Gulf, drain a very extensive area southwards from the Armenian mountain chain which fronts the Black Sea, and bounded west and east by the valley of the Jordan, and the most westerly belt of Persia. No district shows more clearly that the area drained by a river can be spoken of as its basin only with some restriction. The alternately transverse and longitudinal streams which unite in the Euphrates indicate that several basins, or the convergent slopes which shed their waters into one channel, have been opened into each other. If the north and south streams are the primitive courses formed as the land was raised, then the basins of the east and west tributaries are secondary vàlleys, and as such, portions of the one great Euphrates basin; if, on the other hand, the chains of the Taurus and Anti-Taurus formed the waterpartings which constituted the land they bound a water basin, then the Euphrates, which cuts through the southern barrier, drains at least two basins. This is certainly the case with the Indus, the Ganges, and the Brahmapootra, all of which drain valleys in the Himalayan range, or belonging to the Thibetan plateau, and break through the southern rampart of the

Himalayas to reach the low country. The upper and lower courses of all these rivers contrast markedly. The upper descend rapidly from the high grounds of their sources, while in the plain they have lower slopes and a gentler flow. The drainage areas of these rivers are together nearly equal to that of the Mississippi.

The Irrawady and the Saluen, which fall into the Gulf of Martaban, are the principal streams on the east side of the Bay of Bengal. They have not been traced up to their sources, but it is probable that they too descend from the eastern portion of the Thibetan plateau.

131. Southern India: Homomorphic with Africa.—The peninsula of Southern India resembles Africa south of the Sahara, in consisting of an elevated table-land with steep seaward faces, the edges of the plateau rising into hill ranges. The plateau averages from 2,000 to 4,000 feet of elevation, the greater height being in the south. The Eastern Ghauts are lower than the Western, which reach to 5,000 or 6,000 feet on the Malabar coast, while the Nilgherry Hills even attain to 9,000 feet. The form of the mass is that of a pyramid whose base fronts the Himalayas, and is separated from them by the valley of the Ganges, into which part of the drainage flows, and which was once the sea channel that isolated Southern India. But the smaller dimensions of the pyramid have given to the periodic rainfalls a power which has resulted in the formation of streams draining the whole area, and flowing in valleys of denudation often of considerable dimensions. The narrowness of the coast land gives little importance to these streams commercially.

132. Table of Relative Geological Importance of Principal Rivers.—The following table has been constructed with a view to show the relative importance, geologically, of the principal rivers which have been made the basis of investigation by those who seek for a standard of geological time. The known proportions of sediment are assumed to be those which the rivers would offer if they all had the same drainage area as the Mississippi. Of course the student will bear in mind that enlarging the scale of natural phenomena not unfrequently means altogether changing their character. He will, therefore, look on this table as showing the *relative*, not the absolute, proportions for the respective districts:—

Name of River.	Equal Drainage Area in square miles.	Equal Annual Discharge of Sediment in 1,000,000 cubic feet.
Mississippi, ...	1,147,000	7,459
Ganges, ...	,,	15,920
Hoang-Ho, ...	,,	28,908
Rhone, ...	,,	27,600
Danube, ...	,,	6,265
Po, ...	,,	57,380
Nith, ...	,,	2,867
Tay, ...	,,	22,491
Thames, ...	,,	11,980
Forth, ...	,,	12,740
Clyde, ...	,,	5,808
Boyne, ...	,,	26,268

133. Pacific Basin: Eastern Asia.—The Philippine Archipelago, like that of the West Indies, lies to the east of the barrier—here, however, incomplete—which separates two ocean areas. The drainage of the islands, insignificant for the most part, pours into one or other ocean in varying quantities. Thus, while rain falls in Java well nigh throughout the year, and is copious to the east of Timor, the area between Timor and Java, including the eastern part of Kent Island, is dry, the winds blowing over Australia acting towards them as the Sahara to the north coast of Africa.

The eastern drainage area of the continent widens steadily from the extreme north-east till the sources of the Hoang-Ho are distant from the coast line 25° of longitude, while the axis of the Malayan peninsula forms its boundary in the south. As the area widens, the low grounds increase in extent, and are traversed by numberless streams, which give the region great fertility, and are themselves of commercial importance, from the ease with which they can be opened into each other, the canal system of the Chinese Empire enabling every inch of that vast area to be productive. The Hoang-Ho, the Yang-tze-Kiang, and the Amoor, are the three grand streams of this area. The principal facts concerning the Yellow River have been already stated; the Yang-tze-Kiang, or Blue River, has a course of 3,600 miles, and is connected with the Hoang-Ho by canals; the Amoor has a very tortuous course of 2,600 miles from its source S.E. of Lake Baikal, and is navigable by steamers for 2,200 miles. The floods of the Yellow River show some peculiarities, of which no adequate explanation has been given, the possibility being that while the excess of water is in some places spread over swamps, the junction of other streams, whose history is not known, supplies at the flood season an equivalent for the water thus lost from the main channel. The interior of China is accessible for 900 miles by vessels—for the upper 300 miles only by those of small size; but far beyond that limit water transport is still possible. The Song-ha which enters the Gulf of Tonquin, and the Camboja, which enters the Gulf of Siam, have their head waters connected by a canal.

134. Eastern Shores of the Pacific.—The narrow strip of land which skirts the base of the longitudinal mountain chain is intersected by many streams, the waters of which are more copious than their length would lead us to expect. But the catchment basins in the mountains are many and deep; and the Pacific watershed is enlarged by the transverse valleys which drain the great longitudinal valleys seaward. The abundance of the water supply at the sources is testified, as in Africa by the Zambesi, in North America by the Colorado, which flows as a large stream through a more arid region, and enters the Californian Gulf, which is, in truth, the submerged southern end of a longitudinal valley. The streams of Southern America are short, rapid torrents.

135. Australia.—This fragment of a continent, homomorphic with Africa and Southern India, still resembles the former in the fewness of its rivers to the north, and their greater number to the south of the central dry plateau; the northern streams are, further, like those of Africa in their variable character. The Murray River, the largest of the southern streams, receives the Macquarrie and Darling Rivers, and thus drains the inland versant of the Blue Mountains towards the west and south-west in such a way as to suggest a river that once flowed into the central basin of a continent which is now submerged.

The streams of New Zealand are simple; but those of the South Island, whose sources are in the glacier grounds, are slowly extending the fertile low grounds eastward; while the dangers attending their floods promise to advance our knowledge of river phenomena by the engineering precautions which the increasing value of the territory requires.

136. Continental Rivers, or Rivers of Inland Drainage.—Hitherto we have spoken only of the rivers which enter the sea; but a large quantity of the drainage of the land is directed to the interior, forming lakes whose indefinite growth is arrested by evaporation; nay, even their formation is in some cases prevented, and the streams are dissipated in the atmosphere without accumulating. These areas of internal drainage are the interior of Africa, north and south of the equator; the centre of Asia, north of the Himalayas; the Aralo-Caspian area on the confines of Europe and Asia, though it would be perhaps more simple to regard as one the great tract from the Black Sea to the confines of China. But the area is divisible into two, Aralo-Caspian area noting a tract only recently separated from the Mediterranean, while the rest of Central Asia consists of plateaux, which rise to 17,000 feet above the sea level. The Volga and Oural are the largest rivers which enter the Caspian from the north; the former having a course of more than 2,400 miles, and draining an area of 550,000 square miles on the west of the Oural chain, while the Oural has a course of half that length in the east. The Aras (Araxes) drains large part of the Caucasus, while the southern shores receive the torrents from the high lands which bound the Iranian desert to the north. On the east the streams are few, and confined to the extreme north and south ends of the lake, unless the overflow of the Oxus reaches the Caspian about 39° lat. N. The northern and southern extremities of the Aral Lake are the only points at which streams enter—the Amu Daria (Oxus) being at the southern, the Syr Daria at the northern end.

It is impossible in the present state of our knowledge to give any details regarding the number and size of the streams which lose themselves in the deserts, such as the Salt Plains of Iran, in which the river disappears that passes Ispahan. Their history *is a subject of great* interest, since the channels in which water is always present on the margins of these wastes exhibit an amount of erosion only explicable on the supposition that they are the valleys fashioned under other climatal and geographical conditions, the date of which may yet be ascertained.

SECTION II.—WATER IN THE INTERIOR OF THE EARTH.

Lakes: their Classification—Lakes Formed by Irregular Surface Accumulations: by Overflow: by Obstructions: by Glacier Erosion: by Subterranean Erosion: in Areas of Subsidence: by Elevation—Continental Lakes—Analysis of Lake Waters—Ancient Lakes and Lacustrine Areas—Filling up of Lakes.

137. **Lakes: their Classification.**—It is impossible to separate the rivers of inland drainage from lakes, since the conditions which determine the former are the same as those which allow of the formation of the latter.

A lake is a body of fresh or salt water which has no outlet, or whose superficial area greatly exceeds that of its outflow. In these, as in all other natural phenomena, it is exceedingly difficult to draw a sharp line of demarcation, and it may be asked if the Sea of Azof or the Baltic are to be considered as lakes. The only possible answer is that they hover on the border between sea and lake, and that the existence of tidal movements may be held to constitute a real difference. Popular speech has acknowledged the difficulty; for the fiords of the west of Scotland are called lochs, and the distinction between gulf and lake is evanescent when we find that Loch Fyne has a shallow but broad mouth, that the Gareloch has a shallow and narrow outlet, and that the shallow and narrow outlet of Loch Lomond is some miles from the estuary, a difference of elevation giving to each of these three their distinctive characters.

Lakes may be classified as follows:—

I. Lakes which occupy hollows in superficial accumulations—

1. *Lakes formed by irregularity of surface accumulation, as in the*

hollows formed by confluent mounds of sand and gravel; by contiguous morainic mounds; or by sand or shingle bars on the coast.

2. Lakes formed by obstruction, which may be (*a*) temporary when a glacier blocks the mouth of a lateral valley; or (*b*) of greater duration when alluvial gravel or a moraine chokes up a valley, or when a lava stream crosses a river bed; (*c*) lakes of overflow.

II. Lakes which lie in rock basins—

3. Lakes formed, or at least deepened, by glacier erosion.
4. Lakes formed by subsidence: (*a*) when soluble strata have been washed away, letting down the surface; (*b*) when subterranean movements, as earthquakes, allow the surface to subside.
5. Lakes formed by elevation, as may happen when the mouth of a valley in a disturbed district is closed by upheaval.
6. Lakes formed on plateaux, as in equatorial Africa, Asia, and Australia.

This classification cannot be regarded as perfect, since each of these groups may merge into another, the last three being perhaps reducible under one.

138. Lakes formed by Irregularity of Surface Accumulations.—The sand and gravel mounds known as eskers, ösar, or kames (kaims), frequently unite so as to surround cups or grooves in which water may lodge, forming small tarns, as among the great gravel mounds of Carstairs, in Lanarkshire. This also happens among the close-set morainic mounds of glacier valleys. Lagoons are formed by storm accumulations of sand or gravel parallel to the coast, or by the irregular deposit of the materials of a delta, as in that of the Rhone, the *étangs* being due to both of these processes. Lakes of this class are few and insignificant.

139. Lakes Formed by Obstructions.—The parallel roads of Glen Roy, which are the successive beach lines of a sinking lake, illustrate the effects of a temporary obstruction, such as is seen at the present day in the Marjelen See, the barrier of which is a glacier moving across the mouth of the valley. Such a barrier is temporary in this sense, that it depends on climate, an increase of annual average temperature causing its disappearance, whereas detrital barriers are not so removable. Lakes in the course of rivers are often due to inequality in *the texture of the* strata through which the channel is worn, in consequence of which only a narrow groove is cut with difficulty, while above, the softer strata have allowed a wide valley to be formed. The waters held back above the barrier widen the space in which they are contained. But such lakes are obviously of recent origin, as they are of necessity temporary, since the river sediments, speedily deposited in the stiller water, tend to fill them up and convert them into alluvial plains. Some of these lakes are of considerable importance, and should perhaps be referred to the third group, since their features have been, in many cases, exaggerated in temperate regions by the travelling of glaciers down their hollows. Shallower lakes arise by the deposit across a valley of a mass of detritus by a tributary stream; and the same result follows when a glacier pushes its moraine so as to occlude the channel of an adjacent stream. But the grandest examples of such obstruction are to be seen in America, where the pre-glacial river channels have been filled up with boulder clay, the *moraine profonde* of the continental ice-sheet; and, on the disappearance of the ice, the rivers resumed their previous courses. As has been already stated, the great size of Lakes Superior, Michigan, Huron, and Erie, is probably due to this cause, the obliteration of their southward channels ending in their overflow into the St. Lawrence valley. Scrope describes a rare case of the Lake of Aidat, in Auvergne, formed above a lava stream which crossed the bed of the river.

To this group ought to be referred lakes of overflow, where the bed is too small for the flood waters which pour over on the adjacent lower ground. If from any cause the flats into which they pour are limited, a lake may result which will be alternately filled and emptied as the river rises and falls, till at last the river banks may be raised so high that a permanent sheet of water is formed, and this event may be secured by the obstruction of the channel of overflow, as in Louisiana, where rafts of wood sometimes stick at the mouth of the breaches in the river bank.

140. Lakes of Glacier Erosion.—The temperate regions, America north of 45° N. lat., Sweden, Finland, Russia, Scotland, and Cumberland and Wales in England, at the Antipodes (New Zealand), abound in lakes, whose limitation to the leading lines of the valleys of the country is singularly close. Professor Ramsay has proved that to the action of ice a very large number at least of these lakes is directly due. The evidence in support of this view is, first, that the lakes occur in the line of extinct glaciers; second, that the deepest part of their basin is below the level of the channel beyond the outlet; third, that at least in many cases the outlet is through or over a barrier of rock, whose slope down towards the deepest part of the lake is more rapid than that of the upper portion of the lake floor. It is evident that water, even running water, has no power to excavate its channel deeper at one point than at another, more especially when there is not merely a considerable difference of depth at various points of the lake bottom, but, in a large number of cases, the deepest part is below the level of the sea. A lake, in fact, cannot make its own basin; it cannot deepen its own basin in the same way that the Lake of Geneva or Loch Lomond is deepened; its only power is to widen its valley by wearing away the banks at its margin. It has been suggested that many lakes are in the position of former fractures or dislocations of strata; but in very few cases, if in any, is there discord between the strata on opposite sides of the valley. There has been therefore no relative displacement of the mass, such as constitutes a fault; and, even if such difference exists in some cases, it would be necessary to prove that faults as a rule coincide with the line of valleys. But, though instances of such coincidence may be found, faults, as a general rule, traverse a country very irregularly, their dates of origin being anterior to, or subsequent to, the formation of valleys, and their lines without the slightest relation to these results of denudation. This question has already been discussed in treating of the origin of valleys; its special application to the case of lakes is required, because it has even been suggested that lakes have been in some cases determined by the fissure of a fault. But such disruptions of solid rock do not occur as open fissures at the surface of the ground, the mode of their formation (Art. 26) rather making it obvious that the close approximation of the fractured surfaces is the rule; and, though it is quite true that such a fracture line would *be a line of weakness*, and therefore sufficient to determine the course of the stream along it, if the fracture was parallel to the slope of a plain of denudation, it must be remembered that such coincidence cannot be expected to have been very frequent, and, even when it did occur, it would rarely happen that the line of the fault and the course of the primary streamlets coincided.

If we take as an example the large lakes or lochs of the West of Scotland, we shall find that in Loch Long the greatest depth is not in the centre of the loch, but alternately nearer to one or the other side. Especially is this the case below the point at which Loch Goil joins the main valley on the west, where the deepest water is found below the cliffs on the east side. From that point the water slowly shoals from 48 fathoms to 34 near the mouth of the loch, the deepest water being thus found about 6 or 7 miles from the Clyde. In the Gareloch, a vestibule of shallow water exists outside the barrier, so that the 21 fathoms found within the barrier represents a greater depth than is met with in the Firth of Clyde for 4 miles farther down. Near the mouth of Loch Fyne, again, a depth of 104 fathoms has been ascertained; but the opener water for some miles below the point of junction with the estuary does not show more than 85 fathoms. In all these cases, then, we have rock basins, as they have been called—that is to say, lakes resting in hollows of the solid rock—whose greatest depth exceeds that of the channels into which their surplus waters are poured, and whose outflow is over a barrier of solid rock, not of mere superficial detritus. The same facts are illustrated by others of the West Highland lochs, it being especially noteworthy that the line of deepest soundings is deflected at the points of junction of two valleys, and follows also the course which a glacier would have followed in the main valley, approaching alternately to one or the other shore. The example by which Professor Ramsay established his theory—that of the Lake of Geneva—is that of a lake 983 ft. in depth at its deepest part, which is nearly in the centre; a glacier entered the lake with the thickness of not less than 3000 ft., and thus exerted on the comparatively soft rocks of the bottom an enormous vertical pressure, which greatly increased the eroding power conferred by the forward movement of the mass. But, from the point where this grinding action was greatest, it must have diminished in proportion as the ice was melted, in the same way that, at the present time, the lower extremities of glaciers are thinner than the upper; hence the friction which, if continued with equal force, would have sufficed to grind down a whole valley to the same depth, was arrested, and left a hollow, which, when the glacier retreated to its present limits, became filled up with water, and the Rhone now flows out of the lake in an ordinary river valley. It must not be supposed that this theory is applicable to all lakes; all that is contended for is, that it solves the problem of the occurrence in so many regions, where ice has formerly existed in considerable quantity, of deeply excavated basins, whose floor is below the level of the channel of outflow, and in many cases also below —it may be considerably below—the level of the sea.

141. Lakes Formed by Subterranean Erosion.—A few lakes, of small size, arise in some low-lying districts in consequence of subsidence, after the removal of some of the underlying bodies of rock; thus, in limestone districts, underground channels frequently exist, the calcium carbonate having been slowly washed away by water containing decomposing organic matter; and the subsidence consequent upon the breaking-in of the roofs of these underground channels not merely creates a depression, but, by blocking up the subterranean watercourse, forces its contents up to the surface. The removal of solid beds produces a similar effect, whether the removal is natural, as in the limestone districts and where beds of rock salt have been dissolved away, or artificial, as where subsidence follows mining operations.

142. Lakes in Areas of Subsidence.—The Caspian Sea, or lake, as it ought strictly to be called, covers an area as large as Spain, its length being 180 miles, its average breadth 210 miles, and its maximum depth 3,000 feet. Not merely is its surface 83 feet 6 inches below the level of the Black Sea, but if the barrier between the two were submerged, a vast tract of land would be beneath the waters, including Astrakhan and Orenburg. There can be no doubt that this great basin is one of true depression, in which the Aral Lake has to some extent shared. It is about one-fifth of the area of the Caspian; it is 120 feet above the level of that lake, and 37 feet above that of the Black Sea. Its maximum depth, 95 feet, is towards the western side, the eastern portion being shallow. The Dead Sea occupies the southern end of a longitudinal valley, the northern portion of which is drained by a stream which cuts across the valley wall at Belfort, and enters the Levant. The Jordan passes through the fresh water Lake of Tiberias on its way to the salt Dead Sea, whose surface is 1,300 feet below the level of the Mediterranean. The deepest part of the lake is towards the north end, where it is 1,308 feet; at the south end it is only 104 feet. Probably many of the lakes in the interior of continents owe their origin to slow subsidence; but, in defect of evidence, it is safer to speak of their relations without speculating on their origin. One of the best examples of lake formation by rapid subsidence is that of Missouri, in which State the earthquake of 1811—12, felt over an area of 300 miles north and south, let down a tract of 70 to 80 miles north and south, by about 30 miles east and west. Thus the Sunk Country, near New Madrid, is only one of several such depressions in that region, and the cause is still visible in the trenches and sink holes which were opened at the time of the convulsion, water and fragments of rock being forcibly ejected from the latter. The White Water pours into the lake, as does the Mississippi when high in flood.

To this group may be referred a certain small number of lakes, never of any very great size, which occupy the craters of some extinct volcanoes. Their waters are either derived from atmospheric sources, or they are filled from below by subterranean channels. In Trinidad, a lake was formed on the western coast by the subsidence of a patch of land, the hollow becoming filled with a small lake of fluid bitumen; this process having likewise probably originated the great Pitch Lake of that island.

143. Lakes Formed by Elevation.—Some of the lakes found, for example, in the Andes at a height of 12,000 feet may represent local depressions, or, as is possible in that disturbed region, an upheaval of part of the valley floor may have blocked the valley and converted it into a permanent land-locked basin; but evidence is wanting on this subject, and the explanation is suggested because the general features of these valleys strongly resemble those of ordinary valleys excavated by rain and rivers. To this group belong Lake Titicaca and its analogues in the Andes, and Salt Lake in the Rocky Mountains.

144. Continental Lakes.—A large number of lakes cannot be referred with certainty to any of the above-mentioned groups; the topographical details, as well as the geological structure of the areas in which they occur, being unknown or imperfectly known. The great lake region of Africa is possibly in an area of subsidence, at least in part; but the origin of each particular lake is unknown, as their relations to each other are still obscure. Lake Tchad is variable in its dimensions, being in some seasons a shallow lake covering upwards of 200,000 square miles, at other seasons reduced to a marsh, connecting pools. The country in the midst of which it lies is a wide, grassy plain, the monotony of which is scarcely interrupted by a shrub. If the definition of a lake involves the idea of a special basin, Tchad scarcely fulfils this condition. The temporary lodgment of water on the surface of a plain is a frequent occurrence on the plateaux of Africa, Asia, and Australia, and the former existence of such sheets in regions now too arid for the development even of a marsh, is proved by the salt incrustations on the surface left on the evaporation of the water. The following are the principal lakes of Equatorial and Southern Africa:—

	Height above Sea.
Victoria N'Yanza,	3,740, or 3,308, Speke.
Albert N'Yanza,	2,720, Baker; 2,500, Buchan (computed).
Tanganyika,	2,880, Livingstone; 2,800, Finlay (computed).
Liemba,	2,880, Livingstone.
Bemba,	4,000.
Nyassa,	1,522, Kirk.

Whether Tanganyika is in connection with Albert N'Yanza, as Baker was informed by the natives, or is distinct from it, as Livingstone believes, rests still (1873) on the accuracy of the observations of height above the sea, in defect of the practical solution by success or failure in the attempt to pass from the one to the other. The conflicting statements bring into prominence one fact of great interest, namely, that the dimensions of Tanganyika vary with the season. That its waters are fresh, points to its having some outflow free enough to prevent the accumulation of salt in a region where that is the most frequent result of evaporation. The lakes of the Asiatic high grounds have probably very various origins, some lying in glacier lines, others on the plateaux, while others are perhaps due to movements of disturbance which have altered the level of the valley bottoms. The Australian continent has great sheets of water in the interior, their limits being variable, as in Africa; but their extent, comparative fixity, and association with lakes whose supply is permanent, are points on which there is not yet precise information.

145. Analysis of Lake Waters.—Ramsay gives (*Nature*, vol. vii, p. 312) the following table, illustrating the composition of the salts in the water of partially and completely land-locked basins, and the last column shows the composition of those obtained from the Old Well, Bath:—

Percentage.	Mediterranean.	Black Sea.	Sea of Azof.	Caspian.	Dead Sea.	Old Well, Bath. Grains per gal.
Chloride of Sodium,……	2·9460	1·4020	0·9658	0·3673	12·110	12·5
" Magnesium,…	0·3223	0·1304	0·0887	0·0632	7·822	14·5
" Calcium,……	—	—	—	—	2·455	—
" Potash,……	0·0505	0·0189	0·0128	0·0076	1·217	—
Bromide of Magnesium,..	—	0·0005	0·0004	trace		—
Sulphate of Lime,……	0·1357	0·0105	0·0288	0·0490		80
" Magnesium,..	0·2480	0·1470	0·0764	0·1239		—
Bromide of Sodium,……	0·0558	—	—	—	0·452	—
Carbonate of Lime,……	0·0113	0·0359	0·0022	0·0171		9
" Magnesia,…	—	0·0209	0·0129	0·0013		—
Peroxide of Iron,……	0·0004	—	—	—		—
Bicarbonate of Soda,……	—	—	—	—	—	—
Sulphate of Soda,……	—	—	—	—	—	17
	3·770	1·7661	1·1880	0·6294	24·056	133

From these figures it appears that there is a diminution in the proportion of common salt from the Mediterranean to the Caspian, and that the waters of the Dead Sea contain a relatively enormous quantity. The former fact is intelligible when it is remembered that these seas receive a very large supply of fresh water from rivers, and the latter acquires interest from the circumstance that the sole affluent of the Dead Sea is the Jordan, which flows out of a fresh water lake, that of Tiberias.

Lakes have been divided into groups—those which have an outflow, and those which have not. This simple grouping corresponds in some respects to the difference between salt and fresh water lakes. But as the saline character varies, the Caspian and the Dead Seas being very unlike in this respect, the lakes which have no outflow may perhaps be divisible into those which have an abundant supply of fresh water, and those in which it is small relatively to the size of the lake. Since salt is found crystallized or efflorescent wherever sheets of fresh water have evaporated, as in the steppes of Russia, the plains of North Persia, of Africa, America, and Australia, the facts of the Jordan valley justify the provisional generalization that when a lake is fresh the probability is that it has a steady supply and discharge, even though the latter may be secured by percolation through fissures in its basin. Much stress cannot be laid on the apparently exceptional case of the Caspian, for though that lake was probably salter when its separation from the Black Sea was accomplished than it now is, there is reason to believe that its saltness is increasing, evaporation lowering its level more rapidly than the fresh water is poured in.

146. Ancient Lakes and Lacustrine Areas.—Guided by the analogy of existing formations, Mr. Godwin Austen first suggested that the old red sandstone deposits represented lacustrine formations on a large scale. Professor Ramsay has applied this suggestion in the investigation of several geological formations, and has succeeded in showing the probability that most of the red coloured strata have been formed in lakes or inland seas. The red colour due to the presence of salts of iron cannot be explained on the supposition that these strata represent accumulations in the open sea, since all marine strata with which we are acquainted are of various hues, but never red. It is scarcely to be expected that a deposit of peroxide of iron should take place in the ocean, since its diffusion would certainly be immediate. In many lakes, as in those of Sweden, peroxide of iron is deposited; and the old red sandstone, at least of the Scottish type, is an exceedingly local formation. The area which it covers was probably limited towards the south by a barrier of land, which stretched across England from east to west, and which, if prolonged, would pass to the south of Ireland. This barrier was an important one in the carboniferous period, serving to isolate two distinct types of coal formations, though these terrestrial or swamp accumulations are not so distinct from each other as the comparatively unfossiliferous old red sandstones to the north of this line are from the truly marine and abundantly fossiliferous deposits of the devonian series to the south of the British Channel. The old red sandstone rests conformably upon the upper silurians, and the transition from one to the other formation is effected by alternations of gray and red strata, which gradually culminate in the entirely red sandstones. The difference in tint likewise corresponds to a difference in organic contents, and with the gray beds the characteristic silurian fossils disappear. The life of the old red sandstone consists of vegetable remains of terrestrial types, of shells which are closely allied to fresh water families, and of ganoid fishes, whose modern representatives are confined to the fresh waters of the Nile, the North American rivers, the rivers of Australia and of South Africa. The paucity of life on the whole is remarkable; the small size of such shells as do occur, and the absence of characteristic marine remains, give probability to a hypothesis which rests to a considerable extent upon physical and chemical grounds. The permian strata present very many of the same characters; the shells are few in number, the remains of amphibians or terrestrial reptiles are abundant, their footprints being conspicuous where all traces of the body have disappeared. Such plants as are met with belong to terrestrial types; and, when all these are considered, along with the fact that magnesian limestones occur in large quantity—the magnesian carbonate being deposited by evaporation—that gypsum occurs in considerable quantity, and that pseudomorphous crystals of rock salt indicate evaporation in confined areas, while peroxide of iron gives a characteristic tinge to the beds, there is good reason to believe that in the permian we find evidence of the existence of a confined basin, not necessarily a salt sea, but one which, like the Caspian, may have gradually become more saline. The same reasoning would apply to the cambrian and other red-coloured palæozoic strata; but the corroborative evidence derived from the character of the fossils cannot be obtained, in consequence of the small amount of unaltered cambrian strata now exposed at the surface, and the great metamorphism to which the deposits of that age, in England and Ireland, have been subjected.

147. **Filling up of Lakes.**—The history of a lake basin subsequent to its formation is very simple. Every tributary, as well as the main stream, carries down its contribution of detritus, and if the lake is of any size, the sediments have time to subside, at least to a considerable extent, before the waters reach the point of outflow. Delta formations commence, and gradually carry the mouths of the streams farther out towards the centre of the lake, till at last they join the main stream as it flows through the swamp, which the shallowing of the water by deposit tends to form. Thereafter we should have a river flowing through a plain of alluvial materials, and joined by tributaries at various angles. This is the explanation of the frequent occurrence of alluvial plains at various levels in the course of streams. The subsequent events are identical with those that take place in the plains of open grounds, the river gradually cutting its channel deeper into the alluvial soil, shifting its position from time to time, and thus at once deepening its own bed and slowly lowering the general level of the plain.

SECTION III.—WATER IN THE INTERIOR OF THE EARTH.

Conditions which permit its Presence—Springs due to Percolation, or Connection with Volcanoes—Water Supply of London—Limit of Saturation—Pollution of Water—Retentive Power of Strata due to their Character, or to Subjacent Strata—Lodgment of Water—Leakage of Subterranean Reservoirs—Artesian Wells—Yield of Springs—Contents of Spring Water—Mineral and Thermal Springs—Springs in Yellowstone Valley—Thermal Waters in England—Iceland: Theory of Intermittent Springs—Periodic Springs—France and Spain—Bischof's Classification of Springs—Examples of Springs Geologically Interesting—Petroleum Springs—Underground Rivers and Caverns—Contents of Caves—Landslips.

148. The Conditions which permit its Presence.—Hitherto we have treated of water in the form of extensive sheets—oceans; of smaller sheets—lakes and inland seas and of the tributaries of these—rivers. We have now to consider the water held in suspension in the atmosphere, and the various forms under which it returns to the earth. In the present section we shall speak of the circulation of water in the interior of the earth, its movements, its properties, and its results. The quantity of water which sinks into the soil is obviously proportioned to the porosity of the surface, and to the length of time during which it is retained on any particular point. Thus, if water falls on a rock surface, the greater part of it flows off directly; if it falls on sand—supposing that the sand is not overheated, as is that of the desert—it sinks in, and descends vertically, until it is arrested by some less porous stratum.

149. Springs exclusively due to Percolation, or Connection with Volcanoes.—It may be said in general terms that there is a subterranean circulation parallel to that on the surface; and, if there were no curvatures of the strata such as have been described, we should expect to find the largest quantity of subterranean water in the low grounds. The exceptions, however, to this general statement give rise to large number of varieties of springs—varieties both as regard their origin and their chemical properties. Those spring which are more or less intimately related with volcani phenomena illustrate two different sets of conditions; in the one case the springs are directly due to the volcanic action and in the other they are only modified by the vicinity o volcanic activity. Water which sinks into the soil is eithe retained by the strata into which it passes, or, if the quantit of moisture supplied is in excess of their retentive power, i escapes directly, but unseen, into rivers or the sea, or sink to still lower levels, or issues at the surface in the form o springs.

150. Water Supply of London.—The history of the city o London illustrates, perhaps better than any other case, a once the economic importance of underground water supply and the principal geological features upon which that suppl depends. The valley in which London is situated is bounde to the north by the outcrop of the chalk in Hertfordshire, to the south by the outcrop of the chalk in Surrey, and in the hollow thus formed lies the London clay, a mass of lower eocene strata. A vertical section beneath London passes through the following strata:—

Bagshot Beds,
London Clay,
Woolwich and Reading Beds,
Thanet Sands,
and these rest upon Chalk.

Thus there is on the surface a permeable stratum of gravel from 10 to 20 feet in thickness, resting upon tenacious clay of from 100 to 200 feet in thickness, while beneath this retentive mass 70 to 100 feet of sands and gravel are interposed, and the subjacent chalk is itself also porous. The growth of the City of London has been determined by this upper gravel mass, for the ease of obtaining water supply fixes the population necessarily on its surface. Where, to the west and north-west of London, clay is exposed at the surface by denudation, population for a long time was arrested, until artificial water supply was obtained. Again, the river and its tributaries are bordered by a lower lying bed of gravel, and on this again a line of villages sprang up. The population became continuous, and extension into the adjacent districts was possible only when water was conveyed from a distance by conduits. Again, the northern heights of London are composed of sands from 30 to 80 feet thick, which readily yielded a sufficient number of wells for the villages which formerly occupied these sites. To the west, where the Bagshot sands increase in thickness to 300 or 400 feet, the depth to which it would have been necessary to sink for water prevented these localities from being occupied. Finally, where the sands which underlie the London clay crop out at the surface, the line of outcrop determined another series of villages. There is therefore a trough in the centre of which a large quantity of water accumulates, part of it being above and part below the level of the river and of the sea. The water sinking through the gravel which borders the river has its level determined by that of the adjacent stream, and the surplus *would overflow at the* surface if an opening were provided for its escape. But if, either by drought or by an excessive withdrawal of water through these wells, the quantity contained in the porous strata is very much diminished, then the level will sink correspondingly, and none will overflow. (Prestwich, *Quart. Jour. Geol. Soc.*, 1872.)

151. Limit of Saturation.—The limit of saturation, therefore, has a very important effect upon the amount and permanence of water supply. In the centre basin the sands are from 100 to 200 feet below the level of the Thames; at Greenwich, the basin containing these strata is notched to a depth of 100 feet, and below the level of the bottom of this notch the London basin is constantly saturated. The chalk is itself permeable by water, but it is comparatively retentive, since a cubic foot has been found to retain 2 gallons of water by mere capillary attraction, and the water is discharged therefore very slowly. But the chalk is traversed by fissures and broken up by lines of flints; and although these above the limit of saturation are, so to speak, slow conductors of water, the movement below that level is very much more rapid—there is, in fact, a tolerably free circulation. The gradual drainage, by artificial wells, of the strata above the chalk has compelled the penetration of the chalk itself, which now supplies a large part of London south of the Thames. The water is, as has been said, derived from the surface, the rainfall being the most important source; but some is also obtained from the adjacent high grounds, while the river, aided by the rise and fall of the tides, dams back a large body of water at and below its own level.

151. Pollution of Water.—It is obvious that, in addition to the rain, any substances found upon the surface will likewise flow down into this subterranean reservoir; and attention has been called to the fact that around London the old habit of sinking cesspools has contributed a considerable quantity of contaminating matter to the water supply. That these matters travel downwards with exceeding slowness is true, and it must also be remembered that the more distant is the source of the evil from the great body of the water, the greater is the chance of injurious substances being permanently kept back by filtration; but the danger is one deserving of consideration.

153. Retentive Power of Strata due to their Character, or to Subjacent Strata.—The retentive power of strata varies considerably; the case of the chalk has already been mentioned, and the sandstones of the older deposits are perhaps even more retentive than it. It may in fact be said, in general terms, that the return of the water to the surface would be restricted entirely to the escape between the planes of stratification, but for the joints and fissures with which all rocks are traversed. In the case of a conical hill, composed of nearly horizontal strata of which the lowest above the level of the valley is very hard, the quantity of water contained in the hill above the hard bed will present a curve which rises highest in the centre, and has its height determined by the annual rainfall. In such a case springs might be expected to issue at the junction of the softer and the harder rocks.

154. Lodgment of Water.—Where the strata are highly inclined, and especially where they are finely laminated, even though they themselves are not porous, surface moisture will find its way down the stratification planes, and the successive layers of water become connected by the joints and fissures of the strata, so that, following the inclination or dip of the beds, we should expect to find at some point a reservoir, whose place might be fixed with tolerable precision if the strata curved in the opposite direction so as to form a synclinal trough. But in the centre of the trough a fissure, whether due to a fault or to the upward passage of a trap dyke, might form a natural drain for the reservoir, and thus the water might escape to still lower levels.

155. Leakage of Subterranean Reservoirs.—The general proposition that a series of porous strata resting upon an impervious one, more especially when a natural trough exists, will yield a supply of water, is dependent on the contingency of subterranean disturbances, the existence of which may not be indicated by the surface features. But in a series of water-conducting strata, a fault line or a trap dyke may have the opposite effect of damming back the water, and thus forcing it to escape at the surface, and we have, in such a case, a natural Artesian well.

156. *Artesian Wells.*—*These* wells have derived their

name from the place in which they have been so long employed, Artois, in France. The method of sinking an Artesian well is the same as that by which we endeavour to ascertain the presence of underground minerals. Augers, iron instruments, are gradually sunk down by the hand, or, when the depth is great, by machinery, the hard rocks being pounded and the debris withdrawn, and when the instrument at last penetrates into the water-bearing bed, the fluid escapes to the surface with varying force and persistence. If the boring is arrested at this point, the supply may be permanent; if it is carried still farther, the penetration of other reservoirs may yield an increased quantity; but it has happened that the last retentive stratum has been passed through, and the water, instead of escaping at the surface, sinks to still lower levels. The deepest wells in England range from 450 to 550 feet, and the water which escapes from them comes from the chalk hills at least 15 or 20 miles from London. The well of Grenelle, the bottom of which is more than 1,700 feet below the sea level, drains a district above 100 miles distant from Paris, its lowest point being 1,798 feet; that of Passy is sunk to 1,923 feet. The diameters of these bores are various, but the Passy well is 4 feet at the surface and 2 feet 4 inches at the bottom. At La Chapelle, St. Denis, Mr. Prestwich says the bore was commenced 157 feet above the sea level; a shaft, 6½ feet in diameter, was sunk for 113 feet; the bore thence started with a diameter of 5½ feet, and in 1872 had reached a depth of 2,034 feet, with a diameter of 4 feet 4½ inches. It is expected that the lower greensands, the stratum below the chalk, will be reached at a depth of 2,300 feet. While the boring usually goes on uninterruptedly, it happens occasionally that the auger suddenly sinks some distance, and the inference is that the instrument has penetrated into a hollow reservoir. From such a reservoir at Tours were obtained land and fresh water snails and the seeds of water plants, and in Westphalia, under similar circumstances, fish were obtained, these having doubtless come from the nearest streams, situated several leagues away. Desor verified Zickel's observation, that fish were obtained from the Artesian well in the oasis of Aïn Tala, in the north-eastern part of the Sahara; and as these fish are found likewise in the neighbouring pools, it is probable that the pools and the wells are both supplied from a common subterranean reservoir, to which distant streams have contributed by canals wider than simple fissures.

157. The Yield of Springs.—The quantity of water which issues from springs varies considerably. Retentive rock, parting slowly with its contents, will yield in temperate regions a permanent spring, betraying fluctuations only at intervals; thus it has been calculated by Mr. Beardmore that water requires from four to six months to pass from the surface to the saturation level in the chalk, and that the effect of the winter rainfall is therefore not apparent in deep springs before summer. Hence the supply is practically permanent under existing conditions, since the extreme effect of a dry summer and autumn would not be appreciable for sixteen months—that is to say, the storage or reserve of water is more than sufficient to maintain the stream till the effects of the next rainfall are appreciable. More porous strata, through which the transmission of water is rapid, are more liable to fluctuations, and even to intermissions. On the other hand, in limestone, where the water is confined to the plains of stratification, and to the joints and fissures which traverse the rock, the delivery is frequently as rapid as the supply, and the spring therefore is dependent entirely on the rainfall for its maintenance. The yield of the Artesian wells furnishes interesting differences. Thus the well at Fulham, 317 feet deep, yielded 50 gallons per minute; that of Tours discharged 300 cubic yards of water in twenty-four hours. But the force of discharge varies still more. In the Sheerness well the water rose from 328 to 189 feet rapidly; but it required some hours to ascend to 8 feet above the ground. The Chiswick well rose 4 feet above the ground from 620 feet; and one at Tooting did considerable damage, from the force of its discharge, when it was pierced.

158. Contents of Spring Water.—The water seldom escapes pure. Apart altogether from the contaminations already mentioned as resulting from the ignorance, selfishness, and carelessness of men, some wells regularly, others occasionally, give forth the debris of vegetables, indicating that surface matters have from time to time got access to their sources. In other cases, solid inorganic matters are delivered in suspension and in solution. The following table, drawn up by Dr. Frankland, illustrates the varying quantity of materials by weight in 100,000 parts of water, the first column representing the total quantity of carbon and nitrogen in the organic matter. As the effects of filtration are conspicuous in the case of the nitrates, these results must, as Mr. Prestwich remarks, be accepted with caution as indicative of the original condition of the water:—

SOURCES OF WATER.		Organic Elements.	Nitrogen in Nitrates.	Carbonate of Lime.	Total Solid Residue.
Well, Royal Institution, London,...	*Surface Gravel*,..	0·525	4·355	20·8	93·70
„ Royal Mint,................	Tertiary Sands....	0·220	0	7·7	83·96
„ Barclay's Brewery,..........	„ ..	0·065	0·035	4·1	71·56
Thames Water at Hampton,........	—	0·284	0·196	15·7	27·87
Springs, Head of Thames,..........	Oolites,..........	0·023	0·358	17·0	28·25
„ Moorpark,...............	Lower Greensand,	0·040	0·034	0	4·55
„ Otter, near Watford,......	Chalk,..........	0·038	0·422	21·0	32·36
Well, Croydon,..................	„	0·047	0·551	12·9	32·0
„ Caterham,.................	„	0·026	0·027	16·4	31·08
„ Grenelle,..................	Lower Greensand,	0·021	0	6·8	14·09

It appears from this table that the freedom of water from organic matter is in proportion to the depth of the spring; but the facility with which organic matters scattered through the soil are oxidated must be kept in mind; for the conclusion that the source of deep wells is pure would be erroneous, since the purity is only due to the prolonged filtration the waters have been subjected to.

159. Mineral and Thermal Springs.—While no springs are absolutely pure, while the waters always contain a certain amount of inorganic matter, the term mineral springs is employed to designate those in which the mineral matters are either in great excess, or of a kind not usually met in waters. Thus, the silica of the Iceland geysers is not a normal constituent, nor are the arseniates of the African springs. Carbonate of lime, again, is present in most waters, but its excess in the springs of Auvergne and Tuscany, as well as in those which arise in limestone regions, entitle these waters to separate recognition. Again, while all springs of considerable depth have a temperature greater than that of the surface—the increase ranging from 1° C. in 50 to 1° in 80 feet of descent, the highest average of those not associated with volcanoes being 27·7° C.—thermal springs are those whose temperature is in excess of that proper to their depth. Both mineral and thermal springs occur for the most part in districts where there are either active or extinct volcanoes, or in which earthquake phenomena are of frequent occurrence, or, lastly, in localities which have been the seats of very great disturbance.

160. Springs in Yellowstone Valley, North America.—The Yellowstone National Park of the United States, a district about half the size of Wales, presents a combination of phenomena as regards springs which will be more instructive than a series of systematic statements. In this area of 3,575 square miles, recently, geologically speaking, one of volcanic activity, the sedimentary strata are carboniferous, jurassic, cretaceous, and tertiary, the whole resting on metamorphic rocks. Volcanic rocks occupy large part of the area, and as these began to be deposited in tertiary times, the present replacement of the igneous matter by springs issuing from the old craters may be looked on rather as an episode in the life of a volcanic region than a sign of its final quiescence. The floor of the valley in which Gardiner's River (a branch of the Yellowstone) flows is covered with a crust deposited by springs now no longer calcareous, and the slopes are covered with a white crust 20 to 50 feet thick. The water now issuing from beneath this surface layer forms a stream 6 feet wide and 2 feet deep, whose temperature is 55·5° C., but higher up the slope, in basins of 20 to 50 feet in diameter, whose waters are 65·5° to 72° C. The calcareous springs now active contain, in addition to the predominant carbonate of lime, sulphuretted hydrogen, soda, alumina, and magnesia. The siliceous springs are intermittent, boiling, and quiet springs. The waters of the boiling springs are always at 100° C.; they graduate into the intermittent by those in which the water is projected as much as 6 feet at regular intervals. The intermittent are at 100° C. only during activity, falling to 65° C. in the intervals. The quiet springs, once probably boiling, range from 64·4° C. to 26° C.; and it is interesting to note that the deposit of iron takes place at lower temperatures than 65° C., the siliceous sinter showing all gradations of colour, from deep red to the purest white. The mud springs vary in temperature and activity; the mud contains a large quantity of alum, and is kept in movement by jets of steam which toss up the pasty mass to the height of 4 or 5 feet. There is overflow in these craters, and in one where a jet of steam is constantly ascending to the height of 500 feet, the black mud is about 20 feet below the rim of the basin. Sulphuretted hydrogen makes the atmosphere near one spring oppressive. The geysers are most interesting, from the variety of tint and form of the sinter with which their orifice of outflow is surrounded. The column of one rises for 200 feet, and after a quarter of an hour gradually subsides to 2 feet below the mouth of the orifice, the temperature being then 65° C. The waters of this, and the others of the same group, contain as much as 85 per cent. of silica, 11 per cent. of water, 4 per cent. chiefly of chloride of magnesium, with a trace of lime. The association of such varied springs, active and extinct, their generally pulsating character, amounting in some cases to true intermittence, and their association with earthquakes at the present time, in the midst of a tertiary volcanic district—all these indicate the source of the phenomena, but do not explain the chemical variety in the waters, adjacent springs having unlike composition, and affording dissimilar deposits.

In some of these thermal springs there is a large development of confervæ and similar vegetables, diatoms in abundance, and that silky organic matter which it is difficult to refer to animals or plants with certainty. Chemically this *baregin* varies in different springs, but its true nature is not known.

161. Thermal Waters in England.—The waters of the Old Well at Bath, having a temperature of 48·8° C., contain 144 grains of solid matter per gallon. The hot springs of Bristol have a temperature of 20° or 22° C. At Buxton and Matlock there are also warm springs.

The occurrence of calcareous springs in limestone districts has already been referred to. Ferruginous springs are met with under similar conditions: thus the drainage of carboniferous districts sometimes yields ochreous springs, and the water that has drained silurian high grounds (in which there is an enormous quantity of diffused iron) often yields a copious rusty precipitate.

162. Iceland: Theory of Intermittent Springs.—The volcanic region, of which Hecla is the active centre, contains those geysers which were first studied by geologists. The intermittence of these hot springs was long regarded as proof of the existence of reservoirs in which water and gases were heated till the expansion of both raised the fluid in the long tube of the fountain to the level of overflow. The duct then became a syphon, and an interval was necessary before the reservoir was again full enough to permit the process to recommence. In the chapter on Volcanoes it will be shown that Tyndall's explanation of the geysers as slowly but steadily flowing springs, whose waters pass through portions of rock at a high temperature, meets all the difficulties of the case, and, moreover, renders it intelligible that intermittent springs should be of such different chemical character.

163. Periodic Springs.—The alternations of a wet and dry season give one kind of periodicity; but in those specially included under the designation, the recurrence of the flow is at intervals which cannot be thus accounted for. In some cases the existence of a cavern is probable, the outflow being little above the flow. As soon as the water attains a certain level, its duct, bent and syphon-like, drains the cavern to the level of outflow, and then ceases till fresh accumulation repeats the process. In springs connected with volcanic phenomena, the expansion of gases in such a reservoir is likely to take place, and if it occurs is almost certain to furnish periodic phenomena, supposing the supply of water and gas to be constant, and the orifice of discharge not too large.

164. France and Spain.—The volcanic areas in these two countries furnish abundant examples of springs of various kinds. Ansted points out that not all mineral and thermal waters reach the surface of the ground; and his observation accords with what was stated (Art. 27) regarding the course of lavas from the volcanic focus to the surface. In the older strata, especially in the limestones of volcanic districts, we sometimes *find that portions* of the limestone strata have been silicified from below, the alteration presenting a parabolic outline; and the only possible explanation is, that a spring, probably thermal, sought to escape upwards by a joint or fissure, which brought it in contact with a limestone, and there exhausted its energy. The cases to which Ansted refers occur in Auvergne, near Clermont, and in Cornwall—the, so to speak, concealed springs in the latter locality having only been discovered by boring. The calcareous springs of Auvergne are well known, their waters being employed there, as elsewhere, in the rapid production of ornaments, by the deposit of lime in moulds over which the water is conducted. Carbonic acid, boracic acid, carbonates of soda, and even arseniates of soda and potash, are found in the waters of Vichy, the carbonates of soda forming by far the largest ingredient. Sulphur in combination, as sulphuretted hydrogen or sulphate of lime, is of very frequent occurrence, especially in the Pyrennean springs. In Spain the presence of sulphurous springs seem more usually associated with deposits of gypsum (sulphate of lime) than with the presence of volcanic materials.

165. **Bischof's Classification of Springs.**—The substances found in spring water are thus enumerated by Bischof (*Chemical Geology*, i., p. 74), and, as they are usually imperfectly quoted, the list is here given entire:—

1. Saline Bases—Soda, potash, lithia, ammonia, lime, magnesia, strontia, baryta, alumina, protoxides of iron and manganese, oxides of zinc and copper, tin, lead, silver, antimony, arsenic, nickel, cobalt, probably also as oxides.
2. Acids—Carbonic, sulphuric, sulphurous, nitric, phosphoric, boracic, silicic, hydrosulphuric.
3. Halogens and Metaloids—Chlorine, bromine, iodine, sulphur, hydrogen.
4. Organic Substances—Extractive matter (baregin), crenic and apocrenic acids.

And the chemical substances are obtained in different quantities, according to the mode of origin of the spring. Bischof's classification according to origin is the most natural, from the practical chemist's point of view. It is—

1. Springs which originate from rivers.
2. Springs originating in the water which sinks through the beds of brooks and rivers.

3. Springs which originate from elevated lakes.
4. Springs formed by the melting of the snow and ice of glaciers.
5. Mountain springs.
6. Springs from great depths.

166. Examples of Springs Geologically Interesting.—Besides those already mentioned, the following are the best known examples of mineral and thermal waters:—The Carlsbad waters contain 462 grains per gallon of solid matter, and have potash and soda as their dominant ingredients, but they contain also a considerable quantity of metallic compounds. The waters of Aix la Chapelle emit large quantities of nitrogen, probably derived from decomposition; and nitrogen in one combination or another is found in many of the springs in the central plain of Germany. The calcareous waters of France have been mentioned; the source of their lime is obscure, since few of the rocks in that region contain it in large quantity, and the disproportion between the deposits and the apparent source is even more striking in Tuscany, where the deposits are rapid, continuous, and extensive. Italy, rich in regions of volcanic activity, contains many springs whose composition is as various as usual in volcanic regions. The carbonic acid exhalations of the Campagna di Roma, of the famed Grotto del Cane, near Naples, are of the same kind as those of the Limagne d'Auvergne, and among the extinct volcanoes of the Rhine. The enormous quantity of this acid thus disengaged at the surface probably does not represent all that is generated. Considering its power to decompose many rocks, either as a gas or dissolved in water, it is obvious that this gas, derived from below ground, must have an enormous share in the alteration of strata in addition to the work it does when carried down by rain from the atmosphere to the soil. The deposit of silica from hot springs has been mentioned, and the action of warm alkaline waters in maintaining silica in solution is intelligible. But its deposit from cold water is less clear. It appears that such cold springs as form sinters either discharge little water, which forms a stream so shallow as to admit of total evaporation—as perhaps was the case when the veins of rocks were lined, and ultimately filled, with quartz; or, as in the cold *siliceous spring of the Azores*, the mineral is in the form of a double silicate of iron and alumina. It must always be borne in mind that our interpretation of what cold springs do is open to fallacy, since the warm springs of Bagnères de Bigorre became cold after the earthquake of 1660, while that of Bagnères de Luchow, in the Pyrenees, formerly cold, has had a temperature of 50° C. since the earthquake of Lisbon, 1755—two interesting examples of the connection between thermal waters and subterranean disturbances, or, to put it in another form, of the relation which still exists between the volcanic centres and these areas of former disturbance which have long been quiescent. The geological interest of siliceous springs lies in this, that fossilization, as of the wood in the Azores, West Indies, and Australia, is effected on a comparatively large scale by the agency of these underground waters.

167. Petroleum Springs.—The oil wells of America, chiefly found in connection with devonian rocks, owe their origin to percolation, the hydrocarbon compounds being derived from the decomposition of animal and vegetable remains. The borings by which the rock oil reaches the surface either provide a channel for the fluid which travels along the fissures of the strata, or tap reservoirs, just as the Artesian wells reveal the presence of water caverns. It is not always clear why the oil reaches the surface with impetus. The first discharge from a boring is sometimes a quantity of gas with more or less brine, the oil thereafter running pure, so that in some cases, at least, the expansion of gases may be efficient. But the whole history of these springs is still obscure. The upper miocene strata of Trinidad yield the asphalt which gives to the pitch lakes of that island their name. The volcanic rocks of the carboniferous series in Scotland, on the other hand, sometimes retain the products of decomposition, as in the oil shale district of Bathgate, the bituminous matter having doubtless slowly filtered out of the shales. Equally retentive are the fetid limestones, that of the upper silurians at Niagara yielding its bitumen when the limestone is burnt in kilns.

168. Underground Rivers and Caverns.—Underground channels of considerable magnitude are sometimes formed, and their formation is closely connected with the phenomena of springs. The ingulfment of streams is a frequent event, both on the large and small scales, and the phenomenon takes place chiefly in limestone districts, where the percolation of water charged with carbonic acid dissolves away the lime along the lines of fissures. Fractures of strata undoubtedly may, probably often do, take part in fixing the line; but the solvent power of water is sufficient to do the work without much assistance. Bearing in mind what was said (Art. 151) regarding the rate of flow of water through fissures—that capillarity retarded it so long as the fissure was above the level of saturation, but that below that level the water flowed freely, if not rapidly—the genesis of an underground stream is not difficult to follow. The rivers of the Morea, which subside into "swallow holes," or Katavothra, to use the Greek name, emerge near the sea in streams of remarkable uniformity, showing that during the eight months' drought which intervenes between the seasons of rain the subterranean channel is largely supplied from other sources than the swallow holes; or that, as is more likely, the reservoir is slowly drained by narrow apertures, the closure of which, by sediment or by earthquake disturbance, might give rise to a lake in the position of the swallow hole. Similar examples are met with along the north shores of the Mediterranean in the cretaceous limestone, in which the Morean channels are excavated. But the most interesting district is that of Carniola on the Adriatic. There the Timavo rushes at once from the rocks a navigable stream, being fed by underground tributaries from the interior. The caves of Planina, Lueg, and Adelsberg are well known, the principal channel of the last being more than a mile and a half in length, so far as it has been followed. The swallow holes or "dolinas" of this district, the cavities into which the streams sink, form, according to the patency of the mountain streams, and the size of their channels, empty chasms, wells, or lakes—the Lake of Zirknitz (*Lacus Lugens* of the Romans) varying in area from 40 to 80 square miles. This complicated network of channels above and below ground finds its counterpart in other regions. The Hungersee of the Harz Mountains is a dolina like that of Zirknitz; but the great devonian limestone district near Liege is historically and geologically the most important of the cavern *systems*. Dr. Schmerling examined forty caverns, among them the now celebrated Engis and Engihoul Caves, and these, with the series found in the Dordogne and Perigord, have furnished most important evidence as to the former fauna of Southern and Central Europe, as to its arctic character, and the association of man with animal forms now extinct or restricted to the far north of Europe and Asia. In England—where, as in Yorkshire, ingulfed streams are also found, important tributaries issuing directly from the rocks bordering the main river—caverns are also met with whose contents are important contributions to the early history of man. The caves of Settle, Ingleborough, Kirkdale, Denbighshire, of Wokey Hole, Kent's Hole, Brixham, may be mentioned as among those from which remains have been obtained, proving their human occupation at one and, for the most part, at several periods between the time when the reindeer, mammoth, and rhinoceros flourished and the time when men sheltered in them from the Hanoverian troops, or hid therein the smuggled stores which were to cheat the king's revenue. The papers of Buckland, Pengelly, Boyd Dawkins, and others, have given details of those caves hitherto discovered, but their number will be greatly increased as chance reveals openings which debris has concealed. The Mammoth Cave of Kentucky, whose main passage is 10 miles long, while the length of the lateral passages amounts to 240 miles, contains a curious assemblage of animals, the imperfection of whose organs of sight raises interesting questions for the zoologist. A long time was, of course, needed for the erosion of such enormous subterranean caves, but there is no ground for believing that the inhabitants of the Mammoth, the Adelsberg, or the other Carniolian caves have an earlier date than the latest tertiary times.

169. Contents of Caves.—The floors of caves are covered with stalagmite, fine mud more or less calcareous, and breccia, consisting of rounded as well as angular fragments, among which, as well as through the other sediments also, bones and implements may be scattered. One or all of these materials may be present, and each layer may contain organic remains belonging to a different period, though disturbance of the layers may confuse the chronology. In observing such deposits, it is important to bear in mind that the sources of the bones may be various; the occupants of the cave dying, would leave their remains to be covered over by calcareous droppings from the roof, or by the sediments of the stream which still flowed through the cave. An alteration of the level of the cave mouth, or a rise of the stream on whose banks it opened, might allow the flood-borne bodies of animals to be swept in and left there. Fissures might allow the bones of animals to drop in from the surface of the ground, and to become mingled with the older species. Lastly, the Morean rivers show that bones and conglomerate may enter simultaneously, and the cavern will then yield evidence as to the animals which flourished on the surface of the country at periods which cannot be defined.

The hematite deposits of Cumberland are laid down by rivers which have flowed through limestone caverns, the segregation of the iron being due to the action of decaying vegetable matter.

170. Landslips.—Fissures in loose soil or solid rock are traversed by water which may displace more or less of the surface by its excess in a rainy season, by its expansion on conversion into ice, or by the coincidence of either of these with underground erosion, whereby a part of a hill slope or cliff may be made to topple over. The amount and form of the slipped mass depends on a variety of circumstances; but it may be said, in general terms, that those slips which are due to underground erosion have steeper faces than where only surface joints are concerned; and that the harder the rock, and more definite its system of jointing, the more will the characteristic features of such a rock be preserved after the catastrophe. The oblique joints of masses of tough boulder clay furnish an admirable study in the mechanism of springs.

The walls of a valley which a glacier has fashioned describe an elegant and even curve. Those of a valley in which atmospheric waste has been at work in soft, superficial deposits, consist of two parts—the steeper, rockier part, and the more sloping, softer portion; but, where landslips have occurred, the ascent is by a series of lines at different angles, to the more vertical rocky portion. The landslip leaves its mark in a change of slope.

CHAPTER V.

SECTION I.—FORMS OF WATER IN ATMOSPHERE.

Atmospheric Circulation of Water—Atmosphere everywhere Humid—Aqueous Vapour: Evaporation—Amount of Evaporation from Soils and Plants—Condensation—Saturation—Dew, Mists, and Fogs—Fogs of Cities—Height of Fogs: Fogbanners of Hills—Clouds—Condition of Water in Clouds—Velocity of Clouds—Distinction between Dew and Fog—Rainbow—Colour of Clouds—Transport of Aqueous Vapour—Conditions of Rainfall—Relation of Rain to Prevalent Winds—Influence of High Grounds: Homomorphism—Why Rainfall is not Incessant—Dryness of Interior of Continents—Angle of Wind to Land—Polar and Equatorial Winds—Influence of Vegetation—Rain from Clear Sky—Amount of Rain which Flows off the Surface—Periodic, Variable, and Constant Rains—Periodicity of Rainfall—Table of Rainfall.

171. **Circulation of Water in Atmosphere.**—Rain is the form in which, over the largest portion of the world, moisture is restored to the earth, after it has been lifted into the atmosphere from land and sea. In the extreme north and south, precipitation takes place only in the form of snow. In the temperate regions we find seasonal differences, so that snow and rain alternate, while on either side of the equator snow is never encountered except as a precipitation upon the summits of the highest mountain ranges. If we were to connect by a curved line the limits of snowfall in the northern and southern hemispheres, with the limit of snowfall upon the mountains of the equator, we should find that the figure thus described would be that of an oblate spheroid, the poles of which would coincide generally with the poles of the earth; thus a shell of temperature above the freezing point would surround the earth, not parallel to its surface, but rather exaggerating the equatorial protuberance and polar flattening of the globe.

172. Atmosphere everywhere Humid.—A certain amount of moisture is present in the atmosphere even in the hottest regions, with the exception of a few very limited areas known as rainless, and even there an absolutely dry atmosphere probably does not extend to any great distance above the surface. In the Arctic regions themselves, part of the snow-fall is simply the restoration, to the surface, of moisture derived from it.

173. Aqueous Vapour: Evaporation.—Atmospheric moisture is in the form of aqueous vapour. Evaporation means the removal of water into the atmosphere in this invisible form, and as the vapour seldom remains in contact with the surface from which it has risen, there is constantly opportunity for the formation of fresh vapour, the volume of the water correspondingly diminishing. Evaporation is limited by diminution of temperature, or by the confinement of the space into which the vapour is thrown off. The pressure of a very small quantity of aqueous vapour upon the surface of water checks evaporation, and thus furnishes a difficulty not yet solved, since a very considerable atmospheric pressure does not interfere with the process. In cold weather, at the temperature of 0°C. (32°F.), the pressure is ·1811 inches of mercury; at 20°C. it is ·6850 inches; at 50°C. it is 3·622 inches. Trifling as are these pressures, they are enough to arrest the process, though a much greater atmospheric pressure has little or no effect in retarding it. The same effect is produced when evaporation takes place into a confined space, the intervals between the particles of air being occupied by particles of vapour; in other words, the resistance of the vapour being purely mechanical, the atmosphere becomes very speedily saturated, and the water thereafter ceases to diminish in volume, its particles being impeded in their ascent. By the process of evaporation the temperature of water is diminished. Thus the cooling effect of a breeze on the body does not in reality result from the contact of air, but is due to the removal of moisture, to the hastening of evaporation from the surface of the skin. Applying this upon a most extended scale, we find that to evaporation, or rather to the great extent of surface from which evaporation took place *in former times,* was due that extreme amount of cold which rendered the winters of this area more severe, and which prolonged the glacial cold into, geologically speaking, recent times.

174. Amount of Evaporation from Soils and Plants.—It appears from Professor Elliot's experiments, that the rate of evaporation from different soils, depends, in the first instance, on the extent of surface their particles present; and, next, on the compactness of their structure, which increases or diminishes the capillary flow of water from below upwards. While sand lost $\frac{9}{10}$ of its moisture in a given time, clay lost $\frac{3}{4}$, and peat moss $\frac{2}{3}$; the amount has thus a direct ratio to the incoherence of the materials. Moreover, the capillarity of earth is greater than that of moss, hence the evaporation continues longer after the surface has become somewhat dry. The observations of Von Pettenkofer on a growing oak tree show that there is an increase of evaporation from May till July, a decrease thereafter till October; and that the amount of evaporation is 8·33 times greater than that of the rainfall. Hence it follows that a considerable amount of moisture is poured into the atmosphere by vegetation, and that the water is drawn through the roots of the plants from the subsoil. Vegetation thus not merely retards the surface evaporation, but also restores the moisture which some months before had sunk into the deeper parts of the soil.

175. Condensation.—During evaporation, heat is incessantly communicated to the vapour, or, in other words, the separation of the particles which constitute the vapour stores up force. When the heat is withdrawn, when the force with which the particles are kept asunder is overcome, the particles of the water return into contact with each other, liquefaction taking place, or, as it is called, condensation, and the elastic force of the vapour manifests itself as heat. When water is boiled, if the steam is brought in contact with the skin, or with cold water, it is condensed, and the heat becomes apparent by scalding the skin, or by boiling the water into which it is introduced.

176. Saturation of Air.—The saturation point of the atmosphere is that point at which it ceases to be capable of containing more vapour of water. If the atmosphere remains at the same temperature, there is no apparent change, even when the air can receive no more moisture. But if, by lowering the temperature, the elastic force of the vapour is diminished; if, that is to say, the force with which the particles repel each other is lessened, condensation takes place; and the point at which this occurs is known as the dew point.

177. Dew.—For the formation of dew, three things are necessary: air saturated with moisture, a clear sky, and depression of temperature. Any object on the ground which is a rapid radiator parts with its heat into space, and, chilling the air in immediate contact with it, causes the precipitation of the moisture in that portion of air. As the phenomenon is thus due to radiation, it will be affected by anything which modifies that process. In the case of grass, the blades part with their heat, while the moisture in the lower part of their stems prevents its replacement by radiation, as the feeble conducting power of the vegetable prevents its transmission in that way. The passage of clouds across the sky, diminishing the amount of radiation by reflecting the heat, stops the process, as does shelter of any kind, the thermometer beneath Dr. Wells' experimental sheds being 1·8°C. higher than one outside. The necessity for calmness of the air arises from this, that circulation would equalize the loss by radiation, and prevent any one portion from sinking sufficiently low. The temperature of the grass is often as much as 10° to 18°C. below that of the air a few feet above it; and this difference is explained by a convective movement, whereby successive layers become lowered so as to maintain an interval of 2°C. between their temperature and that of the surrounding air. Thus, under favourable circumstances, the deposit of dew would go on steadily, and the injurious effects of low temperature be from hour to hour increased. Hence the necessity of guarding tender plants for some distance above ground from the effects of excessive radiation. In tropical countries, the artificial formation of ice in shallow pans, kept off the ground by dry straw, takes place under the same conditions which determine the fall of dew, and the dry straw, being a bad conductor, prevents the transmission of heat from the soil to replace that lost by radiation; for the process is arrested when the straw becomes wet, and is converted into a good conductor.

It belongs to meteorology to determine the precise temperature at which dew is deposited; it is sufficient here to indicate that the temperature of the dew point varies with that of the atmosphere

178. Mist: Fogs.—The formation of dew only takes place when the aqueous vapour is invisible; but fogs and mists are visible under other conditions. Inequality of surface and movement of the air are, together or apart, essential to bring into contact masses of air, one or both of which are charged with moisture. In a valley in which dew formation might go on if the superincumbent air remained clear, the cold air on the slopes gradually moving downwards turns the balance. It was stated that the atmosphere above the dewy surface is often considerably below the dew point. If other cold, moist air is brought in contact with it, further condensation at once takes place, and fogs are formed such as may be seen creeping from either side of a valley till the whole flat ground is covered. The colour of these fogs varies from the delicate blue, almost transparent, veil, to the dense white mass which saturates the clothes of the traveller. In a very wide plain, like that of Biggar, between the Clyde and Tweed, such a dense mist forms a sea-like surface about three feet deep, above which mounds project like islands, and on these dew may be formed within a few feet above the fog.

The position of lakes and rivers is marked by fogs whenever a considerable difference of temperature exists between the air over them and that on the banks. It is immaterial whether the land or river atmosphere is the colder; whether it is the glacier stream which traverses the warmer low grounds, or the river which flows from warm high grounds to cooler plains. Conversely, when a long strip of land projects into the sea, the inequality of temperature gives rise to fog, which may fringe the bank of land or entirely obscure it. The British Islands repeat this phenomenon on a large scale, with this addition, that the seas they separate are of unequal temperature; in winter and spring, when this difference is at its maximum, fogs prevail.

The direct contact of two masses of warm and cold air is Illustrated off the Newfoundland banks, the Labrador current and the Gulf Stream being accompanied by humid atmospheres whose meeting gives rise to almost constant fogs; and the difference of temperature is as great farther to the south, the waters of the Gulf Stream being proportionally warmer than those of the adjacent sea. In the Pacific Ocean, where a coral bank lies across a current of warm water, the boil up and flow over of the interrupted warm stream maintains a constant temperature in excess of that proper to the latitude, and a correspondingly constant fogbank and rainfall. High grounds at right angles to the prevailing winds, more especially where these travel over a considerable ocean area, are for the same reason the seat of fogs, the coasts of Norway and Peru being notable examples.

179. Fogs of Cities.—London fogs are good examples of interference with natural processes. The artificial heat of the city, and the smoke which, though scarcely obvious to the resident, marks its position at a great distance, combine with the humidity consequent on its proximity to the river to make the coldest months periods of long-continued and dense fogs. Professor J. Thomson has described similar phenomena at Belfast. In all large cities dew and hoar-frost are infrequent as compared with equal areas in smaller towns, or in the country; and the reason of the difference has been put to practical use by the vine-growers, who maintain smoky fires on clear nights to windward of their vineyards, the artificial clouds checking radiation.

180. Height of Fogs: Fogbanners of Hills.—It is difficult to fix the upper limits of fogs. In general, when of local origin, they form a layer which conforms to the undulations of the surface. The fogs which come with the east winds of spring on the shores of Britain are probably of considerable depth. The flat summit of the Campsie hills is the last resting place of these fogs towards the west, and when the low grounds are clear, the fog mass gradually declines from a vertical thickness of about 800 feet to a thin layer, which ultimately disappears. As the height of the range averages 1100 feet above the sea, this would give about 2000 feet, or less than half a mile, as the upper surface of the fog. There is, one may almost say with certainty, an interval between fog and cloud. The connecting link between the two is the *fogbanner, which sometimes* hangs over the ridge dividing two valleys of unequal slope, as may be seen every autumn in the highlands of south and north Scotland; sometimes streaming out from a prominent peak, changing its corm but not shifting its place. These furnish only another phase of what has been already described as the consequence of the contact of two masses of moist air at unequal temperatures. The chill mountain top condenses the atmospheric moisture to leeward of its peak, and as the chilling is increased by the wind the streamer maintains its place, its extremity, however, being dissipated by the wind. The mass is, in fact, constantly regenerated at the peak as it is wasted to leeward. But if the air falls in temperature, the condensation extends till at last a sheet of fog cloud covers the adjacent summits, and creeps downwards over the slopes. But before this general covering is developed, fog masses may become detached and float away on the wind; these "packmen," as they are called in south Scotland, being solitary travellers which surely foretell rainfall. In all hilly countries the evening fog masses take the direction, and often follow closely the form, of the ridges below, and they may be seen by watching, to grow from above downwards till they rest on and finally cap the hills, the clear interval between them and the hills being occupied by moist air, which the slowly-moving breezes (for this is only seen on quiet evenings) gradually condense. These clouds are, therefore, due to terrestrial radiation.

181. **Clouds.**—The distinction is not always attended to between these hill fogs due to terrestrial radiation, and those clouds, properly so called, which result from a cooling process that commences in the upper regions of the air itself. Clouds have been made the subject of very various classifications, but the simplest is that which divides them into three primary groups:—

1. Stratus, the horizontal layers due to the cooling, by radiation, of a mass of air *in situ*.
2. Cumulus, the massive foam-like clouds which form the summits of ascending columns of moist air, condensation commencing with a loss of electric tension.
3. Cirrus, which owes its existence and its light curd-like form to the contact and cooling of two masses of air.

Between these leading forms an endless variety of intermediate steps may be recognised. The stratus, which in Britain is well called the cloud of night, is the dominant form in the central plains of Germany. It is the lowest of the cloud masses, and represents the cooling by radiation of moist air which very slowly ascends. As the sun's rays decrease in power with their obliquity, the aqueous vapour is less and less dissipated; its tension diminishes as the temperature falls, and radiation gradually condenses the upper layer from the east towards the west. The cumulus again is the cooling of a mass of moist air which is, so to speak, poured into the colder upper atmosphere, its form being, as Saussure first suggested, exactly comparable to that of a coloured fluid poured into clear water, and the analogy is often very close when the cumulus masses seem to roll over each other upwards. The cirrus belongs to the highest of the cloud-bearing regions, and its form and movements are a sure index of the direction of the wind within the next few hours at the surface. For the details of the form and significance of clouds, the student must consult special treatises on meteorology, Buchan giving in his *Handbook* an excellent summary of the leading points.

182. Condition of Water in Clouds.—It has been supposed that the cumulus is a frozen mass; but the difficulty, already sufficiently great, of understanding how clouds are supported in the air, is thereby needlessly increased. The movements of masses of cloud, even of the seemingly fixed cumulus of summer, shows that if they approach solidity it can only be by their assuming the state of snow. The edges of the masses are irregular; they are constantly changing, and when precipitation takes place the sudden change of form in the mass immediately above indicates a very great amount of mobility. If they were in the state of ice, we should expect that evaporation under the sun's heat would coat them with a fog layer, which is never the case.

183. Velocity of Clouds.—It is probable that the clouds move much more rapidly than do the lower strata of the atmosphere, even when both are travelling in the same direction. Buchan has observed a velocity at the rate of 72 miles an hour, and quotes Mr. Stephens as having, from twenty observations, calculated 109 miles as the rate. If the highest cirri, the isolated masses of which are most easily made subjects of observation by following their often sharply-defined shadows on the ground, are at 10 miles elevation, even if they are at 5 miles height, their apparent motion may be very much less than their real motion; but the high velocities above quoted have an important bearing on the movements of the upper air currents, as demonstrating in them a to and fro movement, depending probably on the radiation of vapour masses; just as slight surface movements are seen on the surface of the Gulf Stream.

184. Distinction between Dew and Fog.—The clearness of the atmosphere above the surface on which dew is condensed is the consequence of the unequal rate at which the tension of the vapour and of the air diminishes. Before the dew point in the air itself can be reached, the gas must have fallen to the same temperature as the vapour. The formation of fog commences when this happens, as a consequence of the mixing of two masses of air. Clouds begin to appear when the cooling which accompanies expansion reduces the air to the same temperature as the vapour. Neither dew nor fog forms on the thermometer suspended above the ground, the air cooled by its radiation sinking down to the ground as fresh portions take its place, just as the cool air flows down the hill side into the valley.

In the preceding articles an attempt has been made to separate the two kinds of condensation, the one giving rise to dew and fogs in consequence of the cooling by radiation of the earth's surface, and of the air in contact with it; the other giving rise to clouds, properly so called, which result from radiation of vapour suspended in the air, whose temperature is lowered along with its rarefaction.

185. Rainbow: Colour of Clouds.—The spectrum produced by refraction in the drops of condensed vapour is usually double, the inner and the outer having the reds adjacent, the violets being at the extremes. The form of the bow is that of a semicircle when the sun is on the horizon, but the arc becomes less the higher the sun rises, and at 45° the bow is not formed. The occurrence of rainbows against a clear sky, though not frequent, proves the possibility of a considerable amount of condensation taking place in the form of a thin layer not thick enough to obscure objects behind it. The refractive power of the atmosphere gives rise to increasing chromatic changes towards sunset. As the sun declines westward the amount of the atmospheric layer which his rays traverse increases: at noon the vertical thickness is pierced, towards sunset the oblique, almost horizontal, rays undergo greater diffusion and refraction. The absorptive power of the atmospheric vapour depends on its quantity and form, according as it is in the finest state of division, or its particles are aggregated into spheres. The succession of tints at dawn and sunset is due to the changing absorptive power relative to each tint; but this, as well as the details of the refraction and reflection within drops of water, belongs to the department of Physics. Equally beyond the scope of this volume is the discussion of Mock Suns or Parhelia, Mock Moons or Paraselenæ, Halos, Coronas, or Broughs as they are called in Scotland, and Lunar rainbows. These are all due to refraction and reflection on and in masses of vapour; but whether that vapour is in the gaseous, or the vesicular state, or is crystallized, is not certain. In leaving this subject it may be added that the electric and magnetic states of the atmosphere are still comparatively unknown, and that thus influences may be at work whose action and power we cannot at present estimate.

186. Transport of Aqueous Vapour.—The moisture lifted from land and sea does not remain where it has been gathered, but is carried away by the currents of air, which will be described in the next section, and distributed over large areas. In those regions characterised by the prevalence of steady winds, we have this conveyance of moisture regular in certain directions, and thus we have a constant circulation or transfer of water from one region to another, the result of which is the maintenance of equilibrium, the circle being completed by the return of water to sea and land, to make up for the loss by evaporation. Condensation of atmospheric moisture has already been spoken off, but as yet the quantities thus restored to the ground have been small, though since they are incessantly being lifted up and laid down, they are important geological agents, as well as essential to the *wellbeing of plants* and animals.

187. Conditions of Rainfall.—The conditions under which rain is precipitated, are stated by M. E. Renou, as quoted by Buchan.* 1. Two layers of cloud at least: an upper layer, the cirrus, which, being at a great height, is composed of minute ice particles at a very low temperature, probably not higher than − 40° C.; and a lower layer, the cumulus or cumulo-stratus, which has its density increased and its temperature diminished by the descent of the ice crystals of the cirrus. 2. The temperature of the air at the earth's surface as high as possible. 3. The atmospheric pressure notably lower than in surrounding regions. 4. Regular horizontal currents of air allowing the atmosphere to remain a sufficiently long time in a state of unstable equilibrium. 5. A rapid movement of the air tending to re-establish the equilibrium of pressure and temperature, by mixing together the different layers of the atmosphere.

188. Rainfall Greatest near Ground.—A curious imperfection of rain gauges is illustrated in the following tables, constructed by Colonel Ward from observations extending over four years, 1864–7, and Mr. Chrimes, during 1866–7. The amount of rainfall is relative.

Height above Ground.	RELATIVE RAINFALL.	
	Ward.	Chrimes.
0	1·07	...
2 inches	1·05	...
6 ,,	1·01	...
12 ,,	1·00	1·00
24 ,,	·99	...
36 ,,	·98	...
60 ,,	·96	·94
120 ,,	·95	·91
180 ,,	...	·90
240 ,,	·94	·89
300 ,,	...	·88

The explanation of the anomaly, which must be borne in mind if exact comparison is attempted of observations at many different localities, is, that the rain drops enlarge by attracting vapour particles as they approach the ground; that, especially in heavy rains, the water rebounds from the ground and forms a fine spray over it; that the gauge causes eddies in the air, and thus becomes the centre of convergence for a large amount of water particles.

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* *Handbook*, p. 186.

189. Relation of Rain to Prevalent Winds.—Obviously the rainfall and the prevalent winds of a country go together, the direction whence the rain comes being that of the winds. In the British Islands the most abundant rains are found upon the west coast, the westerly and south-westerly winds crossing the Atlantic, and in their way becoming charged with moisture. As the temperature over a great expanse of water is more uniform than that on land, the transfer of a volume of humid atmosphere from the warmer ocean to the colder land area results in precipitation. Other illustrations will be found in the rainfall of Southern India, which comes with the S.W. monsoon; in that of the Peruvian coast, and others. But in these cases the features of the land have something to do with the amount of rainfall.

190. Influence of High Grounds: Homomorphism.—Homomorphism, already referred to in a previous chapter, is well illustrated by the distribution of the rainfall. On the coast of Norway the mean yearly rainfall is 82·12 inches; at Portree, in Skye, 12½ inches fell in thirteen hours in December, 1863. At Coimbra, 118 inches of annual rainfall is recorded, and the quantity diminishes as we pass onwards, the greatest amount being upon the western side of such mountain ranges as project prominently from the plains. In America, on the western side, 89·9 inches are recorded at Sitka; 65 on the west side of Vancouver's Island; 45 at Fort Vancouver on the Columbia river; and only 5 over a large part of the great inland basin. In South America the same excess is found upon the western coast; the same increase as we advance from the equator southwards, and the same diminution of rainfall upon the eastern portion of the land. In Asia the greatest amount of rainfall is at the foot of the outstanding high grounds: thus the Malabar coast intercepts a considerable quantity of rain; the Himalayas arrest an enormous quantity, which is returned to the plains of Bengal. But the total quantity is greatest, and the sifting process exerted by hills on moist air is clearest, in the Khasia district. At Darjeeling, the rainfall between June and September amounted to 120 inches in one year, while as much as 264 inches fell in August, 1841, and the total annual fall has been known to exceed 600 inches. When it is remembered that by the rainfall of a district is meant a layer of water which would cover the district uniformly, supposing it neither to run away nor to become absorbed, nor to evaporate, the meaning of these measurements will be intelligible by stating this last-mentioned quantity as a layer 50 feet in thickness covering a district. And as 1 inch of rain corresponds to 100 tons of water per acre, the quantity of change of the surface which may be credited to rainfall alone is very large. From all these cases it would appear that mountains have a powerful effect in causing precipitation; on the one hand, by arresting the air in its movement, and thus subjecting it to a certain amount of cooling and compression, the result of which is downfall; on the other hand, the air thus arrested rushes upwards, being forced from behind, and passes into a cooler, more rarefied stratum, where precipitation at once takes place. But that this latter ascent of the air is more important than mere cooling by contact, is shown by cases in all hill districts, where, if the hill is low, the rainfall is on the lee side of it.

191. Number of Rainy Days.—In temperate regions it is difficult to say what constitutes a rainy day: ·01 inch in twenty-four hours is that suggested by Symons, and made the basis of Buchan's table.*

Latitude,	60°—50°	161	days per annum.
,,	50°—46°	134	,,
,,	46°—43°	103	,,
,,	43°—12°	78	,,

This table is quoted for the sake of the general relations it suggests; but the total quantity of rainfall may be small or great in proportion to the estimated number of rainy days.

192. Why Rainfall is not Incessant.—The simple fact of the air containing a large amount of moisture does not necessarily involve its downfall, else the trade winds, which are always heavily charged with moisture, would coincide with regions of well-nigh constant rain. The movement of the atmosphere being constant and uninterrupted enables the air to carry its burden, the capacity for moisture being increased the farther it travels. But where, as in what might be called the atmospheric backwater of the Doldrums, the movement of the winds is arrested, precipitation is seen on an enormous scale.

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* *Handbook*, p. 191.

193. Dryness of Interior of Continents.—This stoppage of the wind and constant draining of the atmosphere by contact with elevated ground explains the dryness of the interior of continents. Immediately to the north of the Himalayan chain we have the dry table-lands of Central Asia: the Rocky Mountains border a region in which only 5 inches fall yearly, although a little way off the annual average is as much as 89 inches. Upon the west coast of the British Islands the mean is about 40 inches, rising at some places to 70 inches; upon the east coast 25 inches forms the average. The mean for Russia in Europe is 15, and the effect of the Scandinavian chain of mountains is seen in the 20 inches recorded for Sweden as contrasted with the 82 inches of the Norwegian coast. The same holds true for South America, Western Patagonia being tolerably wet, while Eastern Patagonia suffers at times from excessive and protracted droughts. The central areas of Australia and Africa owe their dryness to the same cause.

194. Influence of Angle of Wind.—While it is true in general terms that the points of greatest rainfall are upon the windward side of high lands, on which prevailing winds blow, a slight modification is traceable to the angle which the wind forms with the trend of the high ground. The greatest rainfall will be where the wind blows at right angles to the coast; but the quantity will decrease in proportion to the obliquity, so that the arrest of the prevailing wind by the high ground may be very slight, and the rainfall will then be due rather to the friction retarding the margins of the moving current.

195. Polar and Equatorial Winds.—It is also a sound general proposition that winds blowing from the poles are, as a rule, drier than those blowing from the equator; and as the westerly winds prevail increasingly from the region of the trades towards either pole, the rainfall upon the western shores is naturally greater than on the eastern.

196. Influence of Vegetation.—Vegetation has a considerable power in affecting the rainfall; and it is now a well established fact that luxuriant forests have a larger amount of precipitation, other things being equal, than other parts of the same region. The cutting down of the timber on the island of Mauritius was a very important one among the influences which suddenly increased the unhealthiness of the island. Sir John Herschel's observation at the Cape of Good Hope illustrates the influence of trees. The fog clouds of Table Mountain frequently hang for some time without any rainfall. But Sir John remarks that in a forest there was heavy rain, though outside the air was simply moist. The explanation is very similar to that of dewfall on grass, the extended radiating surface of the leaves lowering the temperature and causing precipitation.

197. Rain from a Clear Sky.—Rainbows have been mentioned as occurring under this anomalous condition. The fine rain, or serein as it is called, is probably due to local refrigeration of the air, caused by the interference of one current with another, the arrest of motion giving a short time of condensation before the air, takes a new or resumes its old course.

198. Amount of Rain which flows off the Surface.—It has been calculated that one-third or one-fourth of the rain which falls on the surface flows off it, the remainder being absorbed by the soil, or given back by evaporation to the atmosphere.

199. Periodic, Variable, Constant Rains.—The equatorial zone of constant rain is that in which the atmospheric currents are most variable, and where at the same time the results of evaporation are most abundant. The frequent changes of direction cause correspondingly frequent condensation by arrest of movement.

The periodic rains of the trades and the monsoons correspond to the passage of the sun to north and south of the equator, and though great quantities fall within short periods, while the dry season is one of little or no rainfall, these must not be regarded as dry seasons, since the dews are very heavy.

The variable rains characterise the regions to the north and south of the trades and monsoons, including, therefore, all the temperate and polar regions.

200. Periodicity of Rainfall.—J. Norman Lockyer has tabulated the evidence in favour of an eleven years periodicity of rainfall, coincident with the periodicity sun spots and cyclones. Mr. G. J. Symons gives the following table*:—

Maximum Sun Spot years,	1837	1848	1860	1871?
Heavy Rainfall,	1836	1848	1860	1872
Amount of Rainfall,	33·49	35·98	33·34	?34
Per cent. above average,	19	28	18	20
Minimum Sun Spot years,	1833	1844	1856	1867
Small Rainfall,	1834	1844	1858	1868
Amount of Rainfall,	24·52	23·72	22·79	?28·8
Per cent. below average,	13	16	19	+2

TABLE OF RAINFALL.

ENGLAND AND WALES.

WEST COAST.		SOUTH COAST.		EAST COAST.	
Cumberland—		Cornwall,	22-47	Norfolk,	21
Cockermouth,	22	Devon—		York (High Grounds),	40-50
Seathwaite,	113	Sidmouth,	16·64	Doncaster,	21
Lancashire—		Dartmoor,	52·33	Durham—	
Manchester,	30	Plymouth,	45-100	Bishop Wearmouth,	17
Bolton,	40	Dorset—		Northumberland—	
Coniston,	64	Abbotsbury,	18·45	Newcastle,	24
Liverpool,	24·25	Blandford,	29	Shields,	23
Anglesea,	34·5	Hampshire—		INLAND.	
Caernarvon,	54	Aldershot,	16·51	Staffordshire,	23
Montgomery & Merioneth,	54	Woolmer Forest,	26·90	Leicester,	19-26
Cardigan,	37·5	Sussex—		Bedford,	16
Pembroke,	31-40	Hastings,	18·18	Middlesex—	
Caermarthen,	...	Chichester,	32·79	Hampstead,	16·22
Glamorgan,	42	Kent and Surrey—		Winchmore Hill,	23·11
Somerset—		Margate,	16·38	Wiltshire—	
Taunton,	19·06	Cranbrook,	28·90	Chippenham,	18·14
W. Harptree,	36·76			Salisbury,	25·25

Average of 14 stations on W. Coast, 43·33.
" 12 " S. Coast, 30·26.
" 6 " E. Coast, 25·16.
" 7 " Inland, 20·14.

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* *Nature*, Dec. 26, 1872.

SCOTLAND.

WEST COAST.		EAST COAST.	
Isles,	19–59	Fife,	18·25
Mull,	74·5	Midlothian,	16·27
		Haddington,	17·23

Average of 2 stations on W. Coast, 56·75.
„ 3 „ E. Coast, 17·25.

IRELAND.

Waterford,	39·5
Sligo,	38·5
Dublin,	21·75

W. Germany,	20
Sweden,	20

Mr. Symons rightly doubts the importance of the coincidence with cyclonic periodicity, since greater energy of cyclones can hardly be expected to influence the rainfall over the whole globe.

But from a very extended comparison of observations, the conclusion seems justified that the maximum and minimum sun spot years have respectively a larger and smaller number of atmospheric disturbances, ranging from 9 to 12 on the table, Art. 310, and that the rainfall likewise varies. But such annual variation cannot take place without corresponding variations of temperature, and as this would depend on unequal solar radiation, the coincidence empirically ascertained may yet prove to include electric and magnetic disturbances, and to refer all to a common cause.

The following lines, on the adjoining table, taken from Mr. Symon's *Abstract of Rainfall*, 1832–68, arranged according to sun spot years, will illustrate this special relation, and give a fair comparison of the rainfall over the globe.

TABLE OF RAINFALL.

YEAR	British Isles.			France.					Switzerland.		Italy.	Palestine.	India.	Algeria.			Canada.	United States.			S. America.	W. Indies.
	Guernsey.	Greenwich.	Sandwick, Orkney.	Tarn, Bassin de Saint Ferriol.	Haute Garonne, Toulouse.	Basses Pyrénées, Bages Beost.	Courçon, Charente Inferieure.	Paris.	Geneva.	Great Saint Bernard.	Rome.	Jerusalem.	Calcutta.	Algiers.	Oran.	Constantine.	Toronto.	Philadelphia.	New York, Fort Columbus.	Massachusetts.	Marmato, N. Granada.	Barbadoes.
1844	27·7	24·9	32·1	35·3	34·8	52·0	29·8	27·0	34·4	66·1	30·6	..	73·9	41·2	20·8	..	..	38·8	36·4	36·2	88·4	74·5
1848	48·0	30·2	37·8	25·7	30·0	39·6	25·4	24·9	33·5	62·4	25·4	48·2	58·7	40·5	23·1	..	..	..	36·8	30·2	..	62·8
1856	34·4	22·2	27·4	44·6	31·9	48·8	27·4	25·0	41·0	44·1	28·3	94·0	64·2	28·7	20·5	15·4	28·1	..	..	..	..	46·4
1860	48·0	32·0	38·0	29·3	25·8	40·0	37·0	29·4	41·3	56·3	..	..	..	26·5	18·4	23·0	28·0	..	..	..	..	60·4

SECTION II.—SNOW AND ICE.

Snow: Form of its Crystals—Hoar-frost—Snow Flakes—Sleet—Texture and Colour of Snow—Snow as compared with Rain—Limit of Snowfall—Snow Line, or Limit of Perpetual Snow—Height of Snow Line in different Latitudes—Geological Importance of Ice—Temperature and Density of Freezing Water—Density of Salt Water at Freezing Point—Lowering of Freezing Point by Pressure—Influence of Forces applied to Ice—Plasticity of Ice: Glacier Motion—Expansion of Frozen Water: its Geological Effects—Ice Formed by Compression of Snow—Genesis of a Glacier—Unequal Movement of Parts of a Glacier—Structure of Glacier Ice—Comparison of Glacier and Lake Ice—Daily Motion of Glaciers—Curves of Glacier Valley: their Influence on Erosion of Valley—Mean Daily Motion: Seasonal Variations—Variation of Movement at Surface—Variation of Movement below Surface—Retardation due to Compression—Difference of River and Glacier—Bifurcation of Glacier—Crevasses: Bergschrund—Dirt Bands—Diminution of Glacier by Superficial and Terminal Waste—Dimensions of Glaciers—Diminution of Feeding Ground: Surface Waste—Avalanches—Position of Morainic Detritus on Glacier—Part of the Detritus sinks into the Glacier—Moraines of Deposit—Subglacial Stream: Notch in Terminal Moraine—Glaciers at Sea Level—Striation of Glacier Bed—Characteristic Features of Glaciated District—Extent of Ice over Different Regions—Development of Ice Sheet of N. Hemisphere during Glacial Period—Definition of Glacier and Ice Sheet—Ice Sheet formed by Fusion of Local Glaciers—Lower Boulder Clay: the Moraine Profonde of the Ice Sheet—Upper Boulder Clay—Relation of these Two Deposits—Erratics—Pack Ice: Ice Foot—Coast Ice—Ground Ice—Iceberg—Ice Floe—Travelling of Icebergs—Geographical Effects of Icebergs: Striation—Hail—Structure of Hailstones—Relation of Hail to Storms.

201. Snow.—The particles of aqueous vapour in the atmosphere are frozen when the temperature falls below 0° C. The crystalline figures then formed are hexameral. The simplest forms are six-sided rods; more complex combinations are offered by stars, the rays of which consist of simple rods, whose extremities are bevelled into six-sided pyramids. The angles of these rays are 60°, and if secondary rods project from them, these also have an angular divergence of 60°. But this regularity is lost sight of in the secondary ornamentation when that ceases to be rod-like. Petaloid figures may be reduced to the simple six-rayed type, but it is scarcely possible to trace the rectilinear foundation of many of the secondary patterns. Mr. Glashier's figures of snow crystals might easily be mistaken for drawings of the siliceous skeletons of radiolarians, or microscopic protozoa, whose homogeneous body substance is associated with frameworks of the most exquisite beauty, and marvellous regularity. The crystals sometimes form regular hexagonal plates, which may be deduced from the six-rayed stars by increasing the secondary raylets.

202. Hoar-frost. — Crystals are formed after dewfall if the temperature continues to sink; but they are less regular, and they adhere so as to form, not a continuous layer, but a fur of minute pyramids.

203. Snow Flakes: Sleet.—Snow flakes are formed by aggregation of the crystals into masses varying from an inch to a quarter of an inch in diameter. Their adhesion is less perfect the lower the temperature; and boys are well aware of the fact that snow which will not work into balls is always small flaked. Sleet appears to be snow flakes partially melted in their descent, and accompanied by moisture condensed on the surface of the irregular masses.

204. Texture and Colour of Snow.—The variety of surface which the bevelled spicules of a snow crystal offer to the light, yields an infinite play of prismatic colours, which combine into white; while the reflection from the crystals in the walls of cavities, formed by air entangled among the crystals and flakes, contributes to this effect in the same way that salt or sulphate of magnesia is whiter in mass than when in a thin layer. The red and green tint of snow witnessed in the Alps is due to the presence of *Protococcus nivalis*, a microscopic alga.

205. Snow as compared with Rain.—Snow is to water as 1 to 10 by weight on an average; but the small size of the flakes sometimes diminishes the ratio to 1 : 8. In general it may be held that 1 inch of snow is equal to ·1 inch of water. But the effects of snow are not to be thus estimated. Whereas evaporation reduces rapidly the temperature of the soil on which ·1 inch of water has fallen as rain, an inch of snow checks terrestrial radiation because of its low conductivity, and of the air entangled in its mass; and this same fact likewise prevents the evaporation from the surface of the snow affecting the temperature of the soil. Hence a difference of 20° C., or much more, may exist between the soil under snow and the air above it.

206. Limits of Snowfall.—To the south of 30° N. lat. snow never falls in Europe; but the line which marks its most southerly extension is not a straight one. It is, in fact, the isotherm of 11·1° C., and this, like all other lines of equal temperature, passes into lower latitudes over continents; into higher latitudes over oceans. In the Atlantic it recedes to 45°, and over N. America descends to 33° N. lat.; in the southern hemisphere the limit shows similar but less extensive curves, the flexures northwards corresponding to the southern apices of Australia, Africa, and America.

207. Snow Line, or Limit of Perpetual Snow.—The snow over the greater part of the area thus marked off melts after it falls; but as we advance towards the poles the length of time during which it lies, that is, remains unmelted, increases, till, in 78° N. lat., 54·5° S. lat., the heat of summer is unable to remove the winter's accumulation, and the snow is there said to be perpetual. While this is the horizontal limit of perpetual snow, the vertical is at an increasing height above sea level, till, at the equator, it is on the Andes of Quito 15,800 feet above the sea. But the lines connecting the equatorial with the polar limits are not regular any more than are the isotherms; in other words, the shell of air at a higher temperature than 1·6° C. is not of uniform thickness. In the first place, it is nearly at the same height from the equator to 20° on either side of it; thence it declines slowly towards the poles. But the area is unequal in the two hemispheres, since it reaches 23° farther towards the pole in the north than in the south. Further, its height varies under local conditions: thus, it is 4000 feet lower on the south face of the Himalayas than on the north. On the east side of the Andes it is more than 2000 feet lower than on the west. The quantity of moisture determines the amount of precipitation, and it is greater over the plains of Bengal than over the dry, heated Thibetan plateau; greatest over the track of the S.E. trades blowing from the Atlantic; while the steeper, barer slopes towards the north of Asia and towards the Pacific retain less moisture and absorb more radiant heat.

HEIGHT OF SNOW LINE IN DIFFERENT LATITUDES.

	Lat.	Height in Feet.
Spitzbergen,	N. 80°	E. 0 W. 2500
Norway,	71°	2500
......	70°	2900 3350
...... Sulitelma,		3835
......	60°	C.* 4450 I.† 5500
Kamtschatka,	56·30°	5249
Oonalaska, Aleutian Isles,	53·30°	3510
Aldan,	61°	4476
Altai,	50°	7040
Alps,	46°	N. 8500 S. 8885
Caucasus,	43°	11,063
Ararat,	39·40°	14,170
Pyrenees,	42·75°	8,950
Rocky Mountains,	40°–43°	12,500
Etna,	37·75°	9,500
Sierrà Nevada (Spain),	37°	11,200
Himalayas,	28°–29°	N. 19,560 S. 15,500
Abyssinian Mountains,	13°	14,000
Andes of Quito,	0°	15,800
... Bolivia,	S. 16°	17,700
... ...	18°	20,000
... ...	27°	13,800
... Chili,	33°	E. 12,700 W. 14,700
... ...	42·30°	6,010
	43°	6,000
Mount Cook, New Zealand,	44·25°	S.E. 7,800 W. 6,900
Straits of Magellan,	53 30°	3,707
South Georgia,	54·30°	0

* Coast. † Interior.

208. Geological Importance of Ice.—The geographical distribution of ice, as it is popularly understood, in the shape, that is to say, of solid masses of considerable size, is perhaps, from the geological point of view, the least important of all the facts concerning this form of water. Large as are the glaciers of *tropical* and sub-tropical lands, their effects are trifling in comparison with the modifications of the features of a country effected at every point of the temperate regions by the conversion of watery vapour into ice.

209. Temperature and Density of Freezing Water.—Fresh water attains its maximum density at 4°C.; if the temperature sinks below that point fresh water expands gradually as the temperature falls, till the freezing point is attained, at which there is an abrupt increase of volume caused by abstraction of heat during solidification, but without any lowering of temperature.

The lowering of the temperature is effected by convection. When the surface layer has reached its extreme density at 4°C., it sinks to the bottom, and there is a vertical circulation which only comes to an end when, all being of the same density, this vertical motion is no longer possible. If the water now remains still, it may continue liquid even though the temperature sinks considerably below 0°C. But if such lowering takes place, a very slight disturbance will convert the whole mass into ice. But this process is not an indefinite one in water of any depth, and having a considerable extent of surface. Evaporation accelerates the cooling of the surface, and with the continued sinking of the temperature to 0°C., the point of maximum density is passed; thereafter expansion occurs and the chilled water floats. If ice is formed, that also floats, being of less density than the chilled water. The change of behaviour, at a point short of freezing, prevents the fresh waters of the globe being frozen throughout their mass. After a cake of ice is formed its increase is slow, the cake, among other effects, checking cooling by radiation.

210. Density of Salt Water.—But the ocean is differently affected by cold. As has been already said (Art. 74), salt water continues to contract to its freezing point, −3·67°C. (25·4°F.) if kept still, −2·6°C. (27·2°F.) if disturbed.

211. Lowering of Freezing Point.—Professor James Thomson inferred, from the mechanical theory of heat, that the temperature at which water freezes is not a fixed point, but that it must vary with the pressure applied to the water, and communicated by it to the ice in process of freezing or melting. In fact, he found that the freezing point must vary with pressure, just as the boiling point was already well known to do. From experimental data of various kinds he deduced, by theoretical considerations, the result that the freezing point must be lowered by ·0075°C. for one additional atmosphere of pressure applied, and twice as much for two, thrice as much for three, and so on for many additional atmospheres. This deduction was subsequently confirmed experimentally by Sir William Thomson.

212. Influence of Forces Applied to Ice.—Professor Thomson also deduced afterwards, by other theoretical considerations, that any force whatever which tends to alter the form of ice wet with ice-cold water, whether these forces apply to the ice pressures or tensions, that is, pushes or pulls, whether they are twisting or cross-bending forces, must impart to the ice a tendency to melt and to give out its cold, which will tend to generate, from the surrounding water, a corresponding quantity of ice free from the applied forces. This second result, it is to be observed, is quite distinct from the former one, which related to the lowering of the freezing point by pressure applied to the water and communicated by it to the ice; here the forces are applied to and transmitted through the ice alone, and are not communicated to the water at all.

213. Plasticity of Ice; Motion of Glaciers.—From these two principles, and especially from the later of them, he has offered a theory to account for the plasticity of ice, as manifested by the motion of glaciers down their valleys, past all kinds of obstructions and sinuosities. He has pointed out that, whatever part of the ice may be subject to forces tending to change its form, that part must proceed to melt away, and to give out its cold to the surrounding liquid. Each such melting away, and transfer of forces to newly frozen ice, must entail a change in the general dimensions of the mass of ice as a whole, which will constitute a flow of the glacier down its valley. The yielding by melting entails also successions of fractures, either as small fissures or great crevasses, which allow a more general rapid movement than would occur in virtue of the melting and refreezing alone. The fractured masses reunite when pressed together again in the subsequent progress of the glacier. The principles brought forward by Professor James Thomson relative to simultaneous melting and freezing under forces which tend to change the form of the ice, appear to afford an explanation of the process of "regelation," discovered by Faraday, when he turned attention to the fact that two pieces of melting ice will, even in hot summer weather, unite firmly together if left pressing against each other.*

214. Expansion of Frozen Water: its Geological Effects.—Water, when it passes into ice, changes its volume from 1 to 1·099. In the well known experiment, water in a corked bottle is frozen, and the bottle bursts; but if the cork is left out, a plug of ice projects from the neck. As the surface of the earth in temperate regions—and these represent the greater part of the area of the northern hemispheres—is constantly charged with moisture, the freezing and expansion of the water with which the ground is saturated has the effect of loosening its particles, and although no apparent change may be obvious during the frost, when the thaw comes the loose granular condition of the soil is very apparent; nay, we can sometimes even detect an appreciable elevation of the surface to the extent of an inch or two inches above its former level. Such a loosening of the particles prepares them for removal, and thus the agency of frost is one of the most important in atmospheric denudation. In glacier valleys, the surface moraine is derived from the sides of the valley, but this debris is very seldom obtained by the undercutting of the cliffs, the unsupported face of which would then tumble, as happens in river valleys; the rocky fragments are in reality cast off by the rending action of the ice formed in their interstices, which splits them wedge-like, producing ever fresh surfaces.

215. Ice Formed by Compression of Snow.—But the conversion of water directly into ice is only one of the methods of its production. The enormous masses of this material which constitute a glacier, are obtained by the gradual compression of snow till it has passed from the crystalline form into that of solid, transparent ice. The colour of snow is due, as has been said, to the presence between the crystals—entangled amongst the crystals—of air which intensifies the white formed by the blending of the prismatic rays from the crystalline faces; and from the dull opaque appearance of snow to that of clear ice, several transition stages may be observed. The imperfectly consolidated snow constitutes névé or firn, the friable mass of rotten ice of Alpine travellers—found for the most part above the snow line.

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* J. Thomson. *Theoretical Considerations on the Effect of Pressure in Lowering the Freezing Point of Water.* Trans. Roy. Soc., Edin., xvi., 1849. *On the Plasticity of Ice.* Proc. Roy. Soc., viii., 1856-7. *Recent Theories and Experiments on Ice at its Melting Point.* Ibid., x., 1859. *On Crystallization and Liquefaction.* Ibid., xi., 1861.

216. Genesis of a Glacier.—The passage of snow into ice takes place in this way: the snow which falls upon the mountain summit is increased from time to time by fresh precipitation; but in the interval it undergoes diminution by evaporation, which takes place to a very great extent even in the most remote Arctic regions. The supply of snow, however, is in excess of the removal by this process, and thus we have from year to year an increasing residue, which gradually rises higher and higher above the surface of deposit. If the area upon which this increasing mass alights sinks to the low grounds by vertical cliffs, accumulation may go on for a considerable time before any of the mass leaves the surface; but as the depth of snow increases, the pressure upon the lower strata likewise increases, and unless the area is confined, that pressure produces lateral displacement of the lower portion, which then falls over the cliffs. In such an imaginary locality no great amount of ice may be produced, this lateral displacement relieving the vertical pressure. But, in general, the snow alights upon the summits of hills from which gradual slopes descend, and the vertical accumulation, pressing vertically upon the lower strata, displaces them downwards along the line of slope, and thus we have at once pressure acting in two directions—vertically through the mass, and parallel to the surface of the slope, causing the extruded portions to descend to lower levels. But as the vertical accumulation goes on steadily increasing, the portion that descends the slope likewise increases; and by the double pressure, vertically and from behind, the snow is gradually made to pass through a névé stage, and to acquire that of pure solid ice. This descending mass is not, however, uniform in composition throughout; the surface is covered with fresh fallen snow, and we have, therefore, transitions vertically from snow, through névé, into the characteristic glacier ice. The simple push from the feeding ground is speedily exhausted, the motion of the glacier being due to that plasticity which was explained in Arts. 212, 213. The moving mass descends the valleys in exactly the same way that a rivulet descends from the summit of a waterparting, and the glacier therefore has a superficial resemblance to a river, but the conditions of its motion are in contrast with those of the flowing water.

217. Unequal Movement of the parts of a Glacier.—But the surface of the moving mass exhibits features similar to those on the surface of a river, and we can map the appearance in the one case by the movement of the debris which tumbles upon the surface of the ice; in the other case by the foam or drifted material carried forward by the water. In both we have the friction of the moving mass greater at the bottom than at the sides of the stream, and least in the centre at the surface. The motion, therefore, is most rapid at the last-named point, and in consequence we have a series of curves, the convexity of which points down the stream. Hence the detritus in mid-stream arrives soonest at the end of the river, be it of ice or of water.

218. Structure of Glacier Ice.—Glaciers exhibit a stratified appearance, which is due to certain subordinate processes that their materials pass through. In the intervals of snowfall the sun acts upon the surface, and with great intensity at the higher parts of the mountains. It melts the particles somewhat, and forms an imperfectly consolidated layer of greater or less thickness, according as the interval between the successive snow showers is greater or less; the danger of glacier travelling is, therefore, in proportion to the frequency of the snow showers, for the less the interval the softer is the surface. The vertical pressure, already spoken of, thus operates not upon snow alone, but likewise upon imperfectly frozen layers, formed by the consolidation of water—that is, of melted snow particles.

219. Comparison of Glacier and Lake Ice.—The origin and subsequent history of lake and glacier ice being unlike, their structure is likewise dissimilar. The lake ice represents the slow crystallization of the water, and shows a beautiful internal structure when examined in strong light. The crystals of which it is built up are identical with those of snow, and lie in the planes of freezing. The glacier ice, on the other hand, is formed by compression of snow; and in the process the crystalline character is annihilated, yielding ultimately a transparent substance. Moreover, in addition to vertical, there is lateral pressure and motion: the ice mass is broken up internally by the motion, and comes, in fact, to present a granular aspect, not a crystalline one. They stand to each other, as Helmholtz puts it, in the same relation as calc spar and marble, both of which consist of carbonate of lime; but in the former, as in lake ice, the material is regularly crystallized; in the latter, as in the glacier, it is in irregular crystalline grains.

220. Daily Motion of Glaciers.—It is well known that glaciers descend the valleys in which they lie. Their lower end remains at the same place for many years, notwithstanding the incessant melting to which it is subjected, and this fixity can only be secured by a constant supply from above. The fact that the glacier extends beyond the limit of perpetual snow, necessarily presupposes motion. But apart from theoretical considerations, the motion has been observed and registered by recording the movements of the debris on its surface, and by the insertion of posts in lines across the ice. On the Mer de Glace, below Montanvert, the daily motion of pegs inserted in a line from west to east, was found by Tyndall, 12, 17, 23, 26, 25, 26, 27, 33 inches. Higher up, opposite Les Ponts, the posts from west to east showed a movement of 7, 13, 16, 20, 21, 23, 22, 15. Without following all the details of the experiment, suffice it that the shifting of the maximum speed from one side to the other corresponds with bends of the valley; so that glacier and river alike impinge most forcibly on the concavities of the curves in their course. To this extent, therefore, the general statement that the ice in the centre of the surface of the glacier moves *fastest, must* be modified.

221. Curves of Glacier Valley; their Influence on Erosion of Channel.—The significance of the facts just mentioned lies in this, that in some valleys or fiords, such as that of Loch Long, in Argyleshire, the deepest soundings are nearer alternately to one or other side, and that the deviation is greatest below the point at which a tributary glacier entered. Of course this depth cannot fairly be assigned to glacier erosion, unless its amount exceeds that which a river of water is capable of scooping out for itself.

222. Mean Daily Motion: Seasonal Variations.—The maximum speed of the Mer de Glace, observed in these experiments in 1857, ranged from 20 to 33 or 36 inches daily; while the movement at the margins varied from 7 to 15 inches daily. On the tributary glaciers the movement is less rapid; that of the Glacier du Géant showing 11, 13, 5 inches as its lateral and maximum movement along the transverse line; that of the Glacier de Léchand showing 5, 10, 6 inches. The winter motion of the Mer de Glace in 1859 showed, from observations near Montanvert, a speed only half that of the summer months.

223. Variations of Movement at Surface.—It appears from Tyndall's observation,* that not only does the maximum velocity shift towards the concavity of the valley curves, but that the movement is alternately faster and slower along the same line. These irregularities are due to inequalities of the channel in which the ice flows, inequalities such as to make obvious at the surface the frictional resistance to which the obstacle gives rise at the bottom.

224. Variation of Movement Below the Surface.—The diminution of frictional resistance is progressive from below upwards; but the difference of rate of movement in the highest and lowest portions, is proportional to the depth of the glacier. It has been stated that the surface velocity varies, a reduction taking place where, probably, inequalities of the channel diminish the vertical thickness of the ice. An observation of Tyndall's on the Glacier de Géant showed that the motion at 4 feet from the bottom, at 35 feet from the bottom, and at the top was $2\frac{2}{3}$ inches, $4\frac{1}{2}$ inches, 6 inches in twenty-four hours.

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* *Forms of Water*, pp. 67-97.

225. Retardation Due to Compression.—The Mer de Glace is the joint stream formed by the glaciers de Géant, de Léchaud, and de Talefre. The width of these before their union is 2597 yards; but afterwards the three pass through a valley, which at Trélaporte is only 893 yards wide. Below this point the maximum velocities, already referred to, were 20, 23, 34, 25, 27 inches; but in the Glacier de Géant, three points in the length of the stream moved 20·55, 15·43, and 12·75 inches daily, and as the extreme points were 1032 yards apart, the inference seems fair that the compression of the ice in the narrows, and the consequent deepening of its mass, have to do with the retardation, the counterpart of which would be found in a river under similar conditions.

226. Difference of River and Glacier.—Similar as are the movements of fluid and solidified water, one geologically important difference exists. The river is arrested by an obstacle and flows round it, the ice surmounts the obstacle, retaining to a considerable extent its average thickness. The ice is not rigid, neither is it viscous, but it has a certain power of adaptation to the inequalities of its channel, conferred by that plasticity which has been spoken of in Art. 213.

227. Bifurcation of Glaciers.—In one very important particular the glacier differs from the river; for while both are enlarged by the convergence of tributaries, the river only divides in the delta, if it forms one. But the glacier, by virtue of its plasticity, is not arrested, is not always diverted from its course by elevations of its channel. An inequality of surface which would constitute a waterparting between two streams of water, may present no obstacle to an ice stream. The glacier may, however, divide, and its moieties may descend valleys which lead ultimately to different seas. Between the source of the Tweed and St. Mary's Loch, two examples of such bifurcation are recorded in the still fresh moraines. The glacier which occupied the seat of Loch Skene divided on the opposite hill, and the curved terminal moraine shows that one portion went towards the Grey Mare's Tail to reach the Solway, the other descended Winterhope Burn to join the Megget. On the opposite side of the waterparting, the Upper Talla glacier similarly divided, one portion passing to the left, the other passing by Megget to St. Mary's Loch.*

228. Crevasses: Bergschrund.—When the angle of the bed of a glacier changes; *a*, if the bed rises, the ice of the upper stratum passes through a greater space in the same time than that of the lowest layer; *b*, if the bed slopes downwards, the bottom moves through a greater arc in the same time. In the one case the surface is compressed; in the other it is stretched.

The cross fractures, known as crevasses, occur where a change of level takes place, as in the cascade of the Glacier du Géant, where the bed suddenly slopes, and in the Gorner glacier at Zermatt, where the more rapid motion of the mid stream strains the lateral portions, which break when the pull exceeds a certain amount, in other words, when it is greatly in excess of the yielding by melting (Art. 213). The ridges between these transverse fissures may give way under local strain, and originate new fissures connecting the crevasses, the portions of ice thus isolated being known as séracs. The bergschrund is a crevasse formed where the névé adheres firmly to an outstanding precipice, while its lower part is carried forward by the stream; in this, as in the other case, the line of fracture is at right angles to that of the stream.

229. Dirt Bands.—But below the point at which the crevasses are formed, regelation unites the broken surfaces; not uniformly, however, for the portions descend so as to present a series of terraces, just as a faulted mass of rocks presents inequalities of level of its parts. Solar radiation begins to act, and, as the vertical face of the terrace melts at a different rate from the plane surface, alternate bands of pure and of debris-strewn ice result, the latter soon showing the characteristic curves of a stream in which friction retards the lateral portions.

230. Diminution of the Glacier by Superficial and Terminal Loss.—The upper surface of the glacier undergoes diminution by evaporation, and the lower by melting. The sun's heat during the day melts the surface, and the water pours down into the centre of the glacier through the crevasses. The limit of forward movement of the glacier is determined by the temperature of the valley into which it flows, and variations of temperature are recorded by the position of the detritus which falls from the extremity. If the heat of the valley is such that the melting of the ice is equal to its forward movement, the extremity of the glacier is stationary; if the melting is greater than the supply from behind, the extremity recedes; if, on the other hand, the forward movement is in excess of the melting, the glacier advances farther into the valley, and these three stages are illustrated from time to time in the Alps. The rate of movement has been determined by Agassiz, Forbes, Tyndall, and others, and varies from a few inches daily to a few feet. The backward or forward movement of the glacier, or, as it may be more strictly called, the advance or retreat of its lower limit, according to seasonal variations or climatal changes during long periods, is estimated by the position, at the extremity of every glacier, of the detritus which it conveys.

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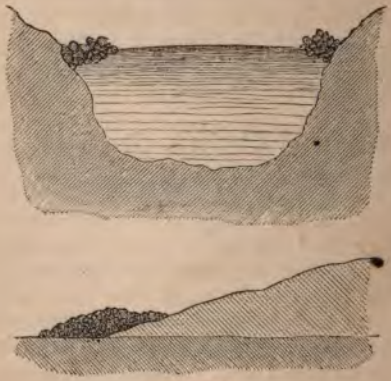
* *Quart. Jour. Geol. Soc.*, 1864.

231. Dimensions of Glaciers.—The length and depth of a glacier depend on the area of the feeding ground, the number and size of tributaries, the amount of snowfall, and the temperature of the valley into which the ice descends. The Alpine glaciers are never more than thirty miles in length at the present day, but the signs of their former greater size are traceable for more than sixty miles from the present end, and their scorings are seen 2000 feet above the bottom of the valley. Nowhere in low latitudes are such dimensions to be found now. Higher average annual temperature, due to secular changes; a drier atmosphere, consequent on man's agricultural operations; hot winds from the Sahara sand desert, in place of the cooler moist winds which crossed the former water surface of that region—all these have tended to diminish the size of the Alpine glaciers. In the Himalayas, a glacier of 36 miles long has been measured, and in New Zealand the great Tasman glacier is 12 miles in length. The Humboldt glacier, in Greenland, measures at the coast 60 miles across, and 300 feet thick.

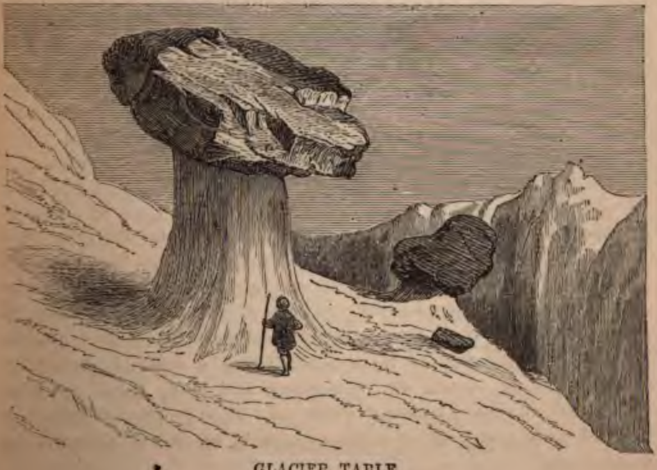
232. Diminution of Feeding Ground: Surface Wash.—In addition to these climatal changes, it must be remembered that the downward passage, even of névé, denudes the rock over which it travels. In all hilly districts on which snow lies for some part of the year, the higher slopes are covered with a quantity of irregular debris, the fragments of which are often irregularly scratched. The snow, slipping from time to time, tumbles these fragments over each other, and they are gradually carried down hill. This surface wash is also met with in glacier districts, on spots too steep for the formation of a glacier. During the long periods that the incipient glaciers have slowly ground their beds, reduction of the snow field or feeding ground must have resulted, and this must be added to the causes of the diminution of glaciers.



MORAINES.

233. Avalanches.—If the slope is too rapid for the snow to accumulate and slowly compress its lower strata into ice, the snow, or it may even be the névé, glides down, when the equilibrium is overthrown. These avalanches are often of enormous size. But ice avalanches also occur when a glacier forms in a hollow, which terminates not in a gentle declivity, but either in a cliff or in a slope too steep for it to rest. The end of the glacier breaks off: if it were in water, it would float away as an iceberg; being on land, it forms an avalanche.

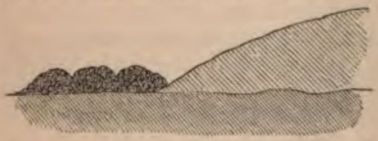
234. Position of Detritus on Glacier.—Moraine is the term used for the rubbish while it is still being borne by the ice. The larger blocks, and the more conspicuous debris, are along the sides of the glacier, being derived from the walls of the valley; and if the glacier remains single, the two marginal lines run parallel nearly to the end. But if two glaciers unite into one stream, the adjacent lateral moraines coalesce, and form a single median moraine. But this union is accompanied by a change of speed; for whereas both lateral moraines were retarded by friction, united they descend with the speed of the central stream. The finer detritus, and the small isolated stones, sink into the ice, being heated by the sun. But all debris in large enough blocks, or in thick enough layers, to permit the slow conductivity of stone to come into play, remains on the surface. As the ice melts, that portion on which the objects rest is protected from the sun's heat; it does not melt, and thus comes to form a pillar or a ridge, with a more or less extensive cap. In the same way, small pebbles protect little cones of sand from rainfall, and thus come to rest on peaks, the intervening hollows being denuded.



GLACIER TABLE.

235. Part of Debris Sinks into Glacier.—But not all the rubbish remains on the surface; part drops in between the ice and the valley wall, part is engulphed in the crevasses. Received into the spongy, slushy ice forming the lowest stratum, the coarse and fine materials are carried forward, grinding and being ground. The sediments resulting from this process are carried out at the end of the glacier by the stream thence issuing, the water of which is derived from the melting of the upper and lower surface of the ice. The coarser materials are detained in the immediate vicinity of the glacier; the finer are carried away and deposited along the course of the river, the distance to which the consequent muddiness extends depending on the speed of the river, or the occurrence of lakes in its course. The loess (löss), which forms so important a deposit in the tertiary series of the Continent, is derived from glacier erosion.

236. Moraines of Deposit.—Two kinds of material are found at the lower end of the glacier, the one distributed mostly in mounds, and consisting of angular fragments of rock in the same state as when they fell from the slopes bordering the glacier; the other consisting of fine mud, of gravel, and of larger blocks, all giving evidence in their rounded edges and smooth surfaces of prolonged friction. The superficial moraine, as the piles of angular rubbish are called, may have the form of a series of cones, each cone corresponding to the line of detritus that has travelled down on the ice; or it may appear as a continuous ridge parallel to the face of the glacier, and sometimes so regular as to look like an artificial embankment. The melting at the extremity of the glacier is not confined merely to its face, but the sides likewise, for a short way up, melt at the same rate, and the rubbish borne at these parts, falling over, constitutes a lateral moraine, which, uniting with the terminal moraine, may form a semicircular barrier round the ice. These piles of angular materials, the size of the fragments in which is often very considerable, rest upon a quantity of deep morainic matter,



As no English word exactly corresponds to the French term, it is perhaps preferable to use it, and speak of the mud and polished stones as constituting the *moraine profonde*. This moraine profonde derives its materials both from the upper and the under surface of the glacier. The heavy mass of ice, travelling slowly along its channel, grinds the surface of the rock beneath, and carries away a certain amount of finely pulverized material. The droppings from the sides of the valley tumble either upon the top of the glacier, or fall into the groove between the ice and the valley wall. Some of the superficial moraine drops into the ice through the crevasses, and ultimately reaches the lower surface; while that which has fallen in at the side of the glacier very speedily gets to the bottom, and each particle, caught up and carried forward by the ice, becomes a powerful agent in friction, disintegrating the surface over which it travels. But the fragments have not the free motion of pebbles in water; and while the latter rolling over and over acquire a rounded form, being smoothed at all points, the glacier-formed stones are usually angular, the angles being somewhat rounded, and one or more of the surfaces uniformly smoothed. The direction of the scratches or striæ upon these polished surfaces tells whether the stone has moved continuously onwards in the same line, or has moved alternately in different lines; in the one case the scorings are parallel, in the other they cross each other. The mud and very fine sand form an impalpable powder, which takes a very long time to settle in water, and this thinner material issues from beneath the ice in a turbid stream.

237. Subglacial Stream—Notch in Terminal Moraine.—There is constant melting going on between the ice and its channel, due to heat developed by friction, to pressure, and the passage of water from the surface into the deeper parts, the evidence of this passage being the fact that a glacier stream is smaller during the night than during the day. In consequence of the permanence of this stream the terminal moraine never forms an uninterrupted mound, but is breached at some point or another, and the finer sediment is carried away to lower points in the valley, the coarser being left behind. If the glacier recedes rapidly, the moraine profonde is spread out as a sheet within the terminal moraine, and has all the appearance of a newly-drained lake bottom. If the recession is slow, rows of terminal moraine form semicircles across the valley, and it is by the distance of the older moraine mounds, from the ice at the present time, that we infer the former extension of the glacier.

238. Glaciers at Sea Level.—To the north of 70° lat. glaciers descend to the coast line. When the ice reaches the sea the detritus it carries is spread out over the' adjacent sea bottom. If the ice is in sufficient mass to push out beyond the shore line, it may travel seawards for some distance in contact with the bottom before it gets into water deep enough to float it. As the specific gravity of ice is such, that for every foot of ice above the surface of water there are about 9 feet below, it is obvious that in shallow seas a glacier may extend very considerably beyond the limits of the land; nay, if the ice is very thick, it may spread over the surface of the sea as a considerable cake before the movements of the water have sufficient power to break it through. Kane speaks of the ice sheet in the Arctic seas as moving up and down with the action of the tide like a door upon its hinges. At some point or other of the floating sheet portions are detached by the formation of crevasses, and these float away as icebergs, carrying with them, adherent to the under surface, such detritus as they may have picked up. Upon the upper surface, animals that have by accident been unable to escape are not unfrequently carried; and in this way fragments of the rocks of one region may be scattered over the ocean floor of another region, and the bones of animals may be found in latitudes to which they are not native.

239. Striation of Glacier Bed.—The friction exerted by a glacier is greatest, obviously, at the bottom of its channel; but the sides likewise are grooved and scratched in exactly the same way, although with diminishing force, as far as the last point of contact of ice and rock. The former greater thickness of glaciers is frequently recognisable from the height at which these lateral longitudinal markings are found above the limits of the present glacier. Glacier denudation is unlike that of rivers, inasmuch as, when an obstacle occurs in its course, the results of friction are entirely confined to the upper side of the obstacle. Thus, we may distinguish the lee side of a projecting mass of rock by its angularity; whereas, in a river, both the upper and the lee side are smoothed, although, perhaps, not equally so.

240. Characteristic Features of a Glaciated District.—The uniform abrading power of the ice gives a characteristic roundness to the inequalities of surface over which it has passed; and thus the centre of Scotland is distinguished by the evenly curved outlines of the hill summits, particularly in the southern districts. The smaller dome-shaped bosses of rock are known as *roches moutonneés*, a term which, however, is equally applicable to the hills.

241. Extent of Ice over Different Regions.—The amount of ice covering particular districts varies considerably. In the Alps, snow and ice cover the central summits and the heads of the valleys, the peaks and ridges separating valleys being frequently entirely free. In Greenland, on the other hand, no mountain peaks are seen projecting; but the whole country is covered with a sheet of ice and snow, which seems to rise inland, and to conceal even the most prominent features of the land. But it must be remembered that little of the interior has been explored, and that fog and haze render unreliable the observations made from a distance. It is possible that Greenland is not a continent, but a series of low-lying islands.

242. Development of Ice Sheet of N. Hemisphere in the Glacial Period.—During the glacial period a sheet of ice covered the whole, even of the more prominent features, of the land in the northern temperate regions. The growth and diminution of this great polar ice-cap was gradual. The increasing rigour of the climate, dependent upon astronomical changes which will be discussed hereafter, permitted the formation of glaciers at first round the central peaks of mountain ranges. As the cold increased these extended into the plains, and, filling the valleys up to their summits, flowed over them, so that adjacent glaciers became united. The land—in some areas at least—went down, and thus the ice covering became universal; enormous tracts presenting the appearance of Greenland. As the climate improved again, and as the land rose above the level of the sea, the ice covering shrank, till at last only limited glaciers remained in the high grounds; and in some parts of the northern hemisphere these also disappeared. Thus, in Britain, the hill districts of Wales, Cumberland, south and north Scotland, still contain the remains of glaciers in the form of moraines, as perfect as if they had been shed yesterday.

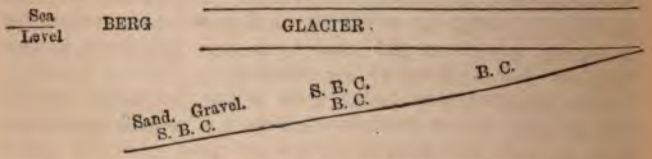
243. Definition of Glacier, and Ice Sheet.—It is convenient to retain the distinction between glacier and ice sheet, notwithstanding the fact that they merge into each other. The former refers to a mass of ice whose movements are controlled by the minor features of a country; the latter to a mass which has overtopped these boundaries, and is no longer controlled by them.

244. Ice Sheet of Glacial Period formed by Fusion of Local Glaciers.—The theory that the ice coverings of all the northern continents originated, each in its own district, and that, as for example in Britain, each separate hill district became a centre for a separate mass of ice, depends for its proof upon the now well-ascertained fact, that the scratchings left by the ice follow the lines of the great valleys, and radiate from the highest points of the country. Not merely do these striæ follow the valleys, but they curve in the valleys in such a way as to suggest a solid body which has been deflected from side to side like a stream of water, only with less sharp curvatures: they repeat, in fact, the deflections indicated (Art. 220) by the observations on the Mer de Glace. The mass of the Scandinavian peninsula shows very beautifully this radiation from the higher grounds. In Britain we find indications that the ice sheet, as soon as it had become continuous, moved without regard to minor inequalities, though still retaining a certain relation to the leading features of the country.

245. Lower Boulder Clay, the Moraine Profonde of the Ice Sheet.—The northern part of the British Islands is covered with a series of accumulations, the lowest of which is a clayey mass, more or less tenacious, according to the amount of shaley strata whose distintegration has contributed materials to it. In this clay are included fragments of rock showing the rounding of the edges, the smoothing and scratching of the flat surfaces, and the frequent limitation of the scratching to one face only; in fact, all the characters which are presented by the *galets* of the modern glacier. These materials, of various sizes and shapes, are thrown together without any order; they are scattered irregularly through the mass, and this, as well as their positions, indicates that they have not been assorted by water. The absence of angular fragments in the mass, though they are frequent on its surface, or to put it more plainly, the fact that all the fragments, large and small, have undergone friction, shows that the till is not the remains of the superficial moraine, but of the moraine profonde. The absence of such unworn fragments as have travelled along the surface of the modern glacier, might have been expected, since, in the first place, the ice sheet at the period of its greatest development covered all the peaks from which fragments might have dropped on its surface; and, in the second place, the shrinking and re-extension of the ice sheet, of which there is abundant evidence, must have given even to unworn fragments their galet form.

246. Upper Boulder Clay, or Stratified Till.—But this unstratified mass is covered in the north of England by a deposit into which it gradually passes, or from which it is separated by a layer of sands and gravels containing marine shells. The stones in this till have evidently the same characters as those of the upper boulder clay, but they show signs of longer friction; and the more or less regular stratification indicates that water has had some share in their reassortment.

247. Relation of the Upper and Lower Boulder Clays.—The accompanying diagram shows how the lower till was deposited by the ice sheet, and how the stratification came to pass. The enormously thick land ice could not have allowed the accumulation of 90 or 100 feet of till beneath it, so long as the whole country was above sea level. But bearing in mind that the ice sheet actually passed far beyond the limits of the land, and that its specific gravity kept it in contact with the bottom for a considerable distance, it is evident that when the depth of water was sufficient to float the ice, an angle was left between its lower surface and the sea bottom, in which the rubbish pushed down by the ice lodged. As the land went down this angle increased, the detritus was deposited in greater quantity, until at last there was sufficient depth of water to allow currents to affect the uppermost part, and to reassort it in a rude fashion. The lower and upper tills are inverse to each other in quantity, as might be expected from the above explanation. It follows, then, that the lower till was not deposited on the land above sea level but below it, and its accumulation in quantity was only possible when the ice was lifted off the sea bottom in consequence of continued submergence.



S. B. C.—Stratified Boulder Clay. B. C.—Lower or Unstratified Boulder Clay.

The diagram represents the glacier from the point where it quits the land.

248. Erratics.—Over all glaciated regions large blocks are found, whose size indicates that they could not have been carried by water, while their shape shows that they have not been subjected to water friction. Some of these have been identified as fragments of rocks, whose locality is so distant that no agent but ice could have transported them to where they are now found. Some of these were doubtless carried on glaciers and left when the ice melted; others must have been carried on icebergs, and dropped when the berg melted, or, as frequently happens, was overturned. Since icebergs at the present time travel in the North Atlantic as far south as the Azores, in the South Atlantic to within 36° of the equator, it is not difficult to understand how, in former times, erratics may have wandered far from the parent rock. These blocks are sometimes found perched on the summits of rocky ridges, in positions where water could not have left them. But it must be remembered that some rocks, as granite, are decomposed by the atmosphere in such a way as to leave *blocs perchés*, exactly similar to erratics, though they have never travelled from the spot. Many of the Logan stones, or rocking stones, of the tors in Cornwall, have this local origin.

249 Pack Ice: Ice Foot.—In the Arctic regions, and in such seas as the Gulf of Bothnia, the surface of the sea itself is frozen for a part of the year. The pack ice, extending seawards, commences at first with the ice foot, a narrow coast belt of ice, sometimes increased to 30 feet in thickness. The sheet becomes broken up by channels, and, under the influence of storms, portions become piled upon each other, constituting masses dangerous to navigation. Geologically, the pack ice is productive of very little change; but the detached fragments may, like the icebergs, become the means for conveyance of animals into lower latitudes.

250. Coast Ice.—Coast ice is rarely formed within the British area, and is, for the most part, met with only where fresh waters are poured into the sea.

251. Ground Ice.—Ground ice, or ice formed at the bottom of rivers, is, in some of the American streams, of considerable importance as a geological agent. The sheet, whose formation is determined by the contact of water with stones at the bottom, which have become chilled by radiation in clear water under a cloudless sky, rises and carries with it the fragments among which it was formed, conveying them down the stream into the open sea, and, as the ice melts, distributing them over the floor of the ocean.

252. Iceberg: Ice Floe.—By ground ice, by icebergs, and, under certain circumstances, by coast ice, very large quantities of sedimentary materials are transferred from one place to another, in addition to the more conspicuous erratics already mentioned. The iceberg is the mass detached from a glacier at the sea level, or broken off from its end at the top of a coast cliff; the ice floe is a part of the pack ice set free by being broken up under the influence of storm waves and tidal movement. The bergs are often of enormous dimensions: even after they have travelled far, a height of more than 200 feet has been seen above water, indicating, if the berg were of equal circumference at all parts, a total height of at least 1800 feet. It has been suggested that the dimensions of icebergs have been exaggerated; perhaps what Mr.

Ruskin calls excitement, when it leads to distorted drawing of hill slopes, is excusable in the circumstances under which the largest reported icebergs were encountered; but if there has been error, the optical phenomena attending their appearance may have had some share in it.

253. Travelling of Icebergs.—Bergs reach the South Atlantic, seemingly across the easterly drift; others traverse the Gulf Stream diagonally. It has been suggested that their mass above water puts them in the position of a ship with sails set, which must sail on the wind. Laughton, without denying this in all cases, suggests that the Antarctic icebergs are carried north by local currents, determined, perhaps, by projections of the unknown Antarctic land; and that the Arctic bergs acquire sufficient "way" to traverse the Gulf Stream, aided, perhaps, if they are deep enough to reach it, by the cold stream which dips under the warm one.

254. Geographical Effects of Icebergs: Striation.—The distribution of detritus and of animal remains has been referred to. The number and frequency of bergs off Newfoundland is believed to have materially increased the height of the Bank, and correspondingly shallowed the water during long ages. The striæ made by bergs were once thought to explain the phenomena of glaciation, now assigned to the action of land ice. The continuity of the striæ under the boulder clay, however irregular the surface may be, could not have been effected by floating ice, which must pass round, but cannot override an obstacle. The desolation of a district by the chilling of the atmosphere during the melting of a large stranded berg, as happened in Shetland, is fortunately a rare occurrence.

255. Hail.—Though hail is one of the forms of water which has been frozen, the circumstances which invariably attend its occurrence entitle it to separate consideration. Hail storms are events of summer and of the day, not happening at night or in winter. They are preceded by slight depression of the barometer, and usually great heat: immediately before the fall a shivering sound is often audible; the barometer rises, and the air is cooler afterwards. They are most frequent within the tropics, diminishing northwards. Mountain ridges seem to influence their severity and frequency.

Obviously the freezing of atmospheric moisture yields the hailstones; but the rapidity with which they have been frozen, judging from the regularity of the crystals, makes it difficult to explain their formation, since the dry condition in which they usually fall indicates that they have been subjected to a temperature far below 0°C.

256. Structure of Hailstones.—They are more or less spherical or oval; and on fracture often very strikingly resemble the zeolites or radiating crystalline minerals found in trap rocks. The crystalline lines are often crossed without being interrupted by concentric lines, such as would result from the freezing of successive layers of water. The size varies from small shot up to masses of an inch in diameter; larger stones—and some of very great size are reported—are formed by adhesion of several, and probably in the extreme cases the regelation took place after they had reached the ground. The freezing probably affects a sphere of water on which more moisture is deposited and freezes, so that when conical pieces are formed these are probably fragments of broken spheres. But in the hailstorm of July 1872, in Glasgow, fragments were caught in large quantities before they reached the ground, and these were conical, with spherical bases, but no trace of concentric arrangement. Their disruption must have taken place in the atmosphere.

257. Relation of Hail to Storms.—Hail in Europe usually comes with a S.W. wind, though local features may shift the direction. The suddenness of the storms, the speed with which they travel, and the restricted area they cover, coupled with the fact that their direction coincides with the usual wind storms of a country, make it probable that, taking place most frequently in tropical regions, and in the hot weather of temperate regions, they are associated with alterations in the electric tension of the atmosphere even when they are not accompanied, as often happens, by a thunderstorm. Whether the cold is that of the upper air into which warm moist air has ascended, or is the result of the meeting of two currents at unequal temperatures, is uncertain.

CHAPTER VI.

SECTION I.—THE ATMOSPHERE.

Composition of Air: its Density—Height of the Atmospheric Column: Ether—Variations of Pressure: Height and Temperature: Aqueous Vapour—Areas of High and Low Pressure—Annual Variations of Pressure—Influence of Aqueous Vapour on Temperature—Absorptive Power of Gases—Influence of Ozone—Temperature of Atmosphere—Decrease of Temperature with Height—Effects of Heat—Analogies of Light, Heat, and Sound—Transmission of Light through the Atmosphere—Transparency and Colour of Atmosphere—Reflection: Refraction: Absorption—Twilight—Absorption: Diminution of Light by Distance—Polarization of Atmosphere—Transmissson of Sound—Intensity of Sound—Sounds louder by Night—Refraction and Reflection of Sound—Resonance—Transmission of Heat—Reflection of Heat—Diminution by Distance.

258. **Composition of Air.**—Having hitherto considered what may be called the proper mass of the earth, all, that is to say, which is essential to the planet as a body moving in space, we have now to inquire into the composition, properties, and movements of the environments of the spheroid. Disregarding, for the time, speculations as to the existence of an ether occupying an apparently vacant space, through which the terrestrial bodies move, we shall confine our attention to the atmosphere, that invisible, elastic layer of variable and uncertain thickness, which surrounds the globe. Perfectly pure air consists of oxygen and nitrogen, in the proportion of 21 to 79 by volume; but this theoretical atmosphere so constantly contains other substances that one is almost in doubt whether the term impurity is legitimately applicable to the compound. Carbonic acid is almost always present; other gases are likewise present in small quantities; and there are, in addition, solid matters of various kinds, organic as well as inorganic. The mixture of the different

gaseous components of the atmosphere is not one which depends upon motion for its completeness, since, if the gases were left in contact without disturbance, a compound would very soon be formed by diffusion. The particles of which this elastic layer is composed are not stationary, either relatively to each other or to the solid globe, and the various kinds of movement, the existence of which we know with certainty, fall to be considered by the meteorologist, who tests the scientific value of his conclusions by the accuracy with which they enable him to foretell atmospheric change.

259. Density of Atmosphere.—If we ascend from the level of the sea to the summit of a mountain, we find that the density of the air is diminished, the pressure, that is to say, is less; and if the height to which we have ascended is 12,000 feet, the atmosphere, which at the sea-level would have occupied a certain cubic space, will, at the greater elevation, occupy double that space. The mode of estimating this difference of pressure is by the barometer, and if the mercury stood at 30 inches at the lower level, it would require 15 inches at the upper level. At the level of the sea the pressure of a column of atmosphere, the height of which is unknown, equals the pressure of a column of mercury 30 inches in height; and as this represents the pressure of about 15 pounds (14·7 lbs.) on each square inch of surface, the pressure at the top of the mountain of 12,000 feet would be about 7⅓ (7·35 lbs.) pounds on each square inch. It has been calculated that at the altitude of between 40 and 50 miles, no appreciable pressure would be detected.

260. Height of the Atmospheric Column: Ether.—If the atmosphere were of equal density throughout, it would be, judging from the mercurial column, five miles in height. But we have seen that the density diminishes with height, and that at 40 or 50 miles no appreciable pressure would be detected. It has been calculated from observations on meteors, which become visible when they penetrate the terrestrial atmosphere, that the upper limit is about 200 miles, while M. Liais, from the phenomena of polarization, fixed it at 212 miles. Within and beyond this limit space is occupied by an elastic medium or ether, which is capable of transmitting the vibrations of light, and of retarding by friction, though the influence be very small, the motion of the celestial bodies through it.

261. Variations of Pressure; Height and Temperature.—The pressure expressed in inches of mercury, that is to say, the height of the column which the atmosphere can sustain, varies under several influences. The diminished pressure felt in ascending to a height is not equal in all parts of the globe. For, as the force of gravity diminishes as the square of the distance from the centre of the earth to any point on its surface, the diminution will be slowest at the equator, most rapid at the poles, the mean being about 45° N. lat. The correction for height is, in Britain, ·001 inch for every 400 feet of ascent; the vertical column of the atmosphere is less by that amount, and ·001 expresses its diminished sustaining power in inches of mercury. To equalize the difference in the rate at which the force of gravity diminishes, the mean point, 45° N. lat., is the zero point; but, at the equator, ·003 inch requires to be subtracted from the observed height; at the poles that amount requires to be added, so as to obtain an average for pressure at the sea level at all points. The temperature of the air modifies its pressure, which is less at high than at low temperatures; but as temperature falls ·55° C. for every 300 feet of ascent, the correction for height is the addition to the observed temperature of a number of degrees corresponding to the elevation.

262. Varieties of Pressure: Aqueous Vapour.—The quantity of aqueous vapour in the atmosphere varies under conditions whose recurrence is determined by the variations of solar influence. In discussing this subject, the student must bear in mind that he will find in these paragraphs only such a general summary as will make him to understand the complicated character of the phenomena on which climate depends, and the consequent difficulty of deciding on the influences to which plants and animals are subjected. The fuller discussion of the phenomena will be found in special treatises, such as Buchan's *Handbook of Meteorology*. Buchan tabulates the diurnal variations of pressure at Calcutta, from which it appears that the greatest pressure, varying from ·039 to ·076, occurs at 9·30 A.M.; the next, at 10·30 P.M., varies from ·008 to ·026: while the minima range from – ·017 to – ·027 at 3·30 A.M.;

from – ·048 to – ·071 at 4·30 P.M. As the tidal wave is later than the time at which the sun and moon cross the meridian of any place, these barometric variations follow periods at which, judged by the sun's position, the daily maxima and minima should occur. The sun crosses the meridian at noon; but as the earth is not rapidly heated, the highest temperature is about three hours later; and the lowest temperature, about 3 A.M., is correspondingly later than the hour at which the sun crosses the antipodal meridian. The highest and lowest pressure correspond to the hours at which the atmosphere contains the greatest and least amount of vapour of water. But though evaporation is greatest at the hottest hours in the afternoon, the pressure is greatest in the forenoon, when the atmosphere has not yet been heated up by solar radiation, and the elastic vapour is therefore retained in its lowest stratum. The afternoon heat relieves the pressure by expansion; the evening cold increases it till dew falls, and thereafter the pressure diminishes till about 3 A.M., when, though the air is coldest, it is also driest. It is obvious that the more nearly equal the daily temperature, or the lower the temperature, the less will be the daily variation of pressures, and the difference is also less marked in uniformly moist climates. But if the moisture is well-nigh equal throughout the year, while the hot and cold of summer and winter are extreme, the barometric variations will be great, as in Siberia, and westwards, into the central plain of Europe.

263. Areas of High and of Low Pressure.—Apart from the influences already mentioned, pressure is modified by some other conditions. Thus, whoever has walked beside a wall on an exposed hill top, while the wind was blowing at right angles to the wall, has seen the dust blown against the wall and obliquely upwards and leewards, or, if the wind was very strong, vertically upwards, while, on the lee side, a slower movement carries dust towards the wall, and upwards along its face to join the main current. This atmospheric backwater is more due to the action of the wind as it passes the top of the wall, tearing off a portion of the leeward air, and thus drawing on a current, than to the curve downward of the air behind the obstacle. To windward the air is jammed against the wall, to leeward it is rarefied: to windward atmospheric pressure is increased, to leeward diminished. By analogy, the weather side of mountain chains might be expected to exhibit increased pressure. This, doubtless, helps to increase the pressure in Siberia, the maximum for that area not being at the place of greatest cold, but to the westward, the Altai and other high lands, whose axis is E.N.E., stopping the west winds and heaping them up; while the area in which Yakutsk lies is, like Eastern Patagonia, a leeward area of low pressure.

264. Annual Variations of Pressure.—The annual variations of pressure are determined by the heat and cold of summer and winter, the former causing an increase of evaporation, thus overcharging the lower strata with vapour; the latter checks evaporation, while the tension is diminished by the more copious precipitation. From the isobaric maps, or maps on which the lines of equal barometric pressures are recorded, it appears that the pressure diminishes towards the poles, but that the area over which pressures less than 29·9 are observed, advances and recedes with the season. Thus, while in July the line of 29·9 is limited by the parallel of 40° S. lat., and the lines of lower pressure are curiously parallel to it, in January the line curves northwards from New Zealand, and gradually reaching lower latitudes in the S. Atlantic, approaches nearest to the equator in S. America about 25° S. lat. The 29·9 line in the northern or land hemisphere is about 50° N. lat. over the Atlantic in January, 55° in July. In the summer this isobaric line curves southwards, over the American continent, nearly to the Gulf of Mexico; over the eastern continent it reaches as far south as the equator; but in both cases it recedes northward as it approaches the Pacific. In winter (January), the line recedes from its lowest latitude over the Atlantic, so as to form a curve whose convexity is towards the poles, while the high pressure follows the great continents. The seasonal influence is therefore well marked. Taking the mean of the year, it appears that maximum pressure (30·1) exists in the north and south Atlantic, in the former stretching across the ocean between 25° and 40° N. lat., in the latter between 15° and 25° S. lat., and that similar areas occur in the Pacific, between 120° and 160° W. lon., and 25° and 40° N. lat., though no equally definite space can be indicated to the south of the equator. A mean annual pressure of 30 inches ranges over North America between 20° and 50° N. lat., while in the Old World it passes obliquely from the south of Europe to the north-east of Siberia. In the southern or water hemisphere, the belt is more nearly latitudinal between 10° and 35° S. lat. A low pressure zone, 29·9, swells out northwards towards the Himalayas, while the same pressure characterises the Arctic area north of 55° lat., the Antarctic area south of 40° lat. The greatest superficial area of high pressure is over the land, of low pressure over the sea.

265. Influence of Aqueous Vapour on Temperature.—The share which the vapour of water takes in the phenomena of atmospheric pressure is scarcely inferior to that which it takes in modifying temperature. Perfectly pure air, consisting only of oxygen and nitrogen, permits all the waves of the sun, luminous and non-luminous, those of light and heat, to pass through; its *diathermancy*, which is to heat-waves what transparency is to light-waves, is perfect; and this is true also for oxygen, hydrogen, and nitrogen. A sun-beam concentrated on ice, after passing through a globe of water, is not apparently affected, yet it has no longer the power of melting the ice; and if the positions of the two "forms of water" were reversed, the same result would ensue. The want of diathermancy is therefore due to the presence of water, not to the mode in which its particles are aggregated. Several very important consequences follow from this fact. The temperature of dry air is not affected by the passage of the sun's rays through it; it is at once transparent and diathermanous. While, therefore, the face is blistered by the direct rays of the sun on an Alpine glacier, the traveller has only to step into the shadow of a rock to realize the fact that the temperature of the air is in reality at the freezing point. This, of course, is only true where the air is greatly rarefied, expansion lowering the temperature. But even at great heights the air is comparatively, not absolutely, dry in glacier districts, evaporation taking place freely from the surface of the ice. The capacity of the atmosphere for heat is therefore in proportion to the aqueous vapour it contains. Air is, however, heated by contact with warm surfaces, and, expanding, rises, colder and heavier air taking its place. The molecular motion produced in dry air by a heated piece of metal is very different from that due to the passage of heat-waves through moist air. Again, the same layer which, as Tyndall puts it, filters the rays of heat due to solar radiation, so that they do not reach the earth, arrests the passage of heat radiated from the earth. It appears from Tyndall's experiments, that "the aqueous vapour of the air from (several) localities exerted an absorption seventy times that of the air in which the vapour was diffused;" and that at least 10 per cent. of the terrestrial radiation is arrested within 10 feet of the earth's surface. From these facts it is clear that while the earth's loss of heat by radiation cannot be so great as it would be were the air perfectly dry, solar radiation does not contribute so much as it would on the same hypothesis. Further, the greatest possible proximity (Art. 349) of the earth to the sun would not secure the melting of the polar ice, since the evaporation due to the great heat would interpose a sieve which filtered the heat rays, and saved the remaining ice from melting.

256. Absorptive Power of Gases.—But the air contains other matters than oxygen, hydrogen, and aqueous vapour. Carbonic acid and ammonia are also present, and both of them present in greater quantity during warm than cold weather. The importance of these gases will be apparent from the following table, taken in part from that of Tyndall:*—

	Relative absorption at 1 inch of pressure.
Air,	1
Oxygen,	1
Nitrogen,	1
Hydrogen,	1
Chlorine,	60
Bromine,	160
Carbonic Oxide,	750
Carbonic Acid,	972
Nitric Oxide,	1590
Nitrous Oxide,	1860
Ammonia,	5460
Sulphurous Acid,	6480

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* *Heat as a Mode of Motion*, p. 320.

Striking as is the proportion of heat rays, or calorific rays, arrested by air and ammonia respectively, the power of arresting the passage of radiant heat exercised by perfumes is even more remarkable. In a series of experiments on aromatic herbs, detailed at p. 335 of the above-quoted work, it is shown that the following relations exist:—

	Absorptive Power.
Air,	1
Thyme,	33
Peppermint,	34
Spearmint,	38
Lavender,	32
Wormwood,	41
Cinnamon,	53

Allowing for the minute exaggeration in these results due to the presence of aqueous vapour, it still appears that interference with the passage of heat rays is enormously out of proportion to the quantity of solid matter which the perfumes of these plants contain. The vegetation of tropical regions is less characterised by the brilliancy of its tints than is that of temperate regions. In the latter, evaporation spreads a protective curtain against the solar radiation; in the former, the development of perfume by plants after sundown will tend to check terrestrial radiation. Insignificant as these observations may appear to be, they are brought under the notice of the student for the purpose of showing him how many are the points to be taken into consideration before we accept as final any judgment on the rate at which the earth receives or parts with heat. The absorptive power of carbonic acid given above establishes, apart from other reasons, the impossibility of an atmosphere of that gas having existed during carboniferous times, the plants of which we have every reason to believe were physiologically identical with those of the present.

267. Influence of Ozone.—This gas is an allotropic form of oxygen, is, in fact, condensed oxygen, capable of effecting oxidations which the elementary gas cannot. It is easily decomposable by heat, its atoms resuming, after expansion, their relations as oxygen, but its absorptive power is 165 times greater than that of oxygen.

268. *Temperature of Atmosphere.*—The sensation of heat or cold is relative, like that of salt and sweet, or any other pair of contrasting impressions. The traveller descending from the Alps complains of heat at the same place where the ascending traveller suffers from cold; the impression conveyed by the same degree of actual temperature is determined by the previous conditions.

Statements founded on mere sensation are open to all kinds of fallacy, only instrumental observations are reliable. The popular saying, that "as the day lengthens the cold strengthens," means, when interpreted by science, that as the drier atmosphere of frosty weather is succeeded by a moister and warmer state of the atmosphere, the great conductivity of the moisture, whereby heat is rapidly abstracted from the body, chills the body, notwithstanding that the thermometer is steadily rising. The contrasting heat and cold on the Alpine glacier have already been mentioned, the air having the same temperature in sunshine and shade.

The thermometer records the varying amount of heat contained in the complex substance, atmospheric air; and the influence of aqueous vapour is not separated from that of other substances. The temperature of the air of the desert sometimes rises to 51·6°C., this being due, however, to the quantity of superheated sand particles suspended in it. This is an extreme case of the phenomenon of heating by convection, or the successive transfer of masses of heated air. Contact with warm surfaces raises the temperature of the lowest stratum of air, the amount varying with the humidity. In short, the temperature of the atmosphere is for the most part expressive of the amount of other substances besides oxygen and nitrogen contained in it, and the most potent of these foreign bodies are aqueous vapour and fine sand.

269. Decrease of Temperature with Height.—The observations of Mr. Glaisher made during balloon ascents (*British Association Reports*, 1869), show that the estimate above given—·55°C. for every 300 feet of ascent—though fairly representing the facts for air in contact with the ground, is not correct for the air away from that kind of disturbing influence. It appears that there is considerable irregularity in the decrease, consequent on the number of atmospheric currents. At a height of 24,000 feet, the temperature in September was −17·7°C., and at 37,000 feet it was −24·39°C. At lower elevations, it would appear that the ratio of decrease is slower; and that within 1000 feet it is affected by the state of the sky, being ·55°C. for 223 feet when the sky is cloudy, for 162 feet when it is clear.

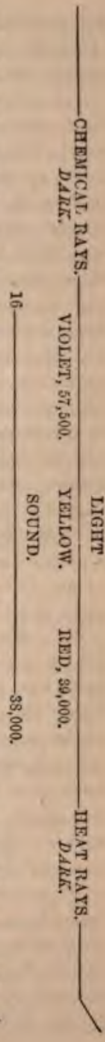
270. Effects of Heat.—The expansion of the air under heat amounts to $\frac{1}{273}$ of its volume for every 1°C. ($\frac{1}{490}$ for every 1°F.), so that if a cubic foot of air be heated 273°C., it will double its volume. The co-efficient of expansion, or the fraction by which the volume of a gas is augmented, when its temperature is raised 1°C., is ·00366 for hydrogen, ·00367 for air and carbonic oxide. If a cubic foot of air is raised from 0° to 273°C., its volume is doubled; and 1·29 oz. of air is capable of raising through 1 foot the weight of 15 lbs. to the square inch, or 2160 lbs. of atmospheric pressure. But if the expansion is prevented, and the volume of the air kept constant, there is a difference in the absolute quantity of heat received by the two cubes of air. A greater amount is required to enable the air to overcome the resistance offered by pressure to its expansion than when the air is heated within unyielding boundaries; in other words, the air which is prevented from expanding has no work to do, the air which expands under pressure does work: it lifts a weight, and heat is spent in doing this over and above that needed for the given quantity of air. The proportion is 1 : 1·421; that is, if the cube with constant volume requires one part of heat, the cube which expands when heated under pressure requires 1·421 parts. The excess is spent in doing work. To take again the cube of air: the lifting of 2160 lbs. through one vertical foot, is the work done by the excess of heat over that needed to raise the temperature of the cube to 490°F. (273°C.). The excess would be sufficient to raise 2·8 lbs. of water 1°F. of temperature, so that dividing 2160 by 2·8, it follows that 771·4 lbs. would be lifted 1 foot by the amount of force which is made use of in raising 1 lb. of water 1°F. in temperature. Such was Mayer's calculation; Joule has corrected this result, and fixed the amount at 772 lbs. This, the mechanical equivalent of the heat, is known as the unit of heat, as a foot-pound; and the *quantity of heat* received by solar radiation at different points of the earth's surface is frequently expressed in these units or foot-pounds. Joule's equivalent is, in terms of the centigrade scale, 1390 foot-pounds for 1° C.

The increase in volume of heated air corresponds to the diminution during cooling: that which has been heated in a confined space parts with its heat when it is allowed to escape and expand. Rarefied air is chilled during expansion, its heat being parted with in the motion of its particles. If the weight which the heated air lifted during its expansion descends during its cooling and contraction, the amount of energy parted with is that of temperature, *plus* that due to the impulse given to the particles by the weight. Ascent of heated and descent of cooled air, are thus incessant and supplemental of each other. If priority is to be claimed for either phase of the cycle, heating may be regarded as the first step, since if the air were uniformly cool, there would be no cause of disturbance. The replacement of warm by cold air is not always effected by two equal parallel movements. If a heated chamber is opened, the expanded air rushes out, is checked, and chilled; there is a reflux of cold air, and thus a succession of pulses occur before equilibrium is established between the air within and that outside the room. The movements are more simple when there is free space for the opposite movements.

271. Analogies of Heat, Light, and Sound.—Heat, light, and sound are vibrations of the particles of bodies; and these are made manifest to our senses by the movements which they impart to the elastic medium between them and our organs of sense. Light and heat are both given off by the sun, and experiments have been already referred to which show that it is possible to stop the one set of vibrations, and allow the other to pass. The independence of light and heat has been asserted by Melloni, but it seems now satisfactorily demonstrated that the solar spectrum represents a series of vibrations of particles or waves, the length of which permits them to be sensible to the human eye as colour; that the length of the waves diminishes from the red to the violet, and that beyond these visible rays other waves exist, those beyond the violet having too short, those beyond the red having too long, a wave length to be visible to the eye.

Finally, the invisible rays beyond the violet are powerful to excite chemical action, those beyond the red produce heat. The vibratory nature of sound is known from the action of the tuning fork, of the violin string, or, to take a more familiar illustration, the result of drawing the teeth of a comb across the edge of a piece of paper. The range of sonorous vibrations capable of being detected by the human ear, varies very widely in different individuals, either naturally or by practice. The limit of appreciation of sound is very wide, ranging, according to Helmholtz, from 16 to 38,000 vibrations in the second, vibrations slower or more rapid than these, respectively, being inaudible. But the series of audible vibrations is very wide, extending over eleven octaves; whereas of the visible rays of light, the shortest vibrations are not quite half the length of the longest. The analogy between these four kinds of vibrations is very interesting; in strictness, there are only two sets of phenomena to compare, light and sound being respectively the centres of two series, of the extremes of which we are only made conscious by their effects.

It appears from what has been stated that our conceptions of external influences on living things would be very imperfect, and necessarily erroneous, if we considered only those phenomena which are capable of direct interpretation by our senses. Recalling the wide sphere which at the outset we claimed for Physical Geography, it is obvious that the student of that science has only done a portion of his work when he has estimated the effect on living beings of physical features, of movements of the earth's crust, or of the circulation maintained in the atmosphere and the ocean.

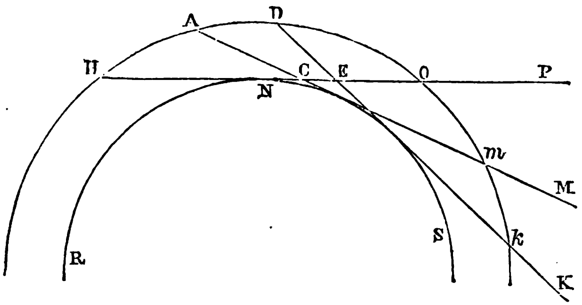


272. Transmission of Light through the Atmosphere. — Light travels at the rate of 192,000 miles a second, as inferred from observations on the occultation of Jupiter's satellites; or 184,000 miles according to the most recent experiments. Their obscuration appears to occur about a quarter of an hour (16m. 26s.) later when the earth is at the opposite side of its elliptic orbit from the planet, than when it is at the nearest point of that orbit to the planet; and as the diameter of the orbit is about 190,000,000 of miles, the light of the occulted body takes 15 or 16 minutes to traverse that distance. But this speed is liable to be modified by the density of the atmosphere. By the undulatory theory, according to which the vibrations of the luminous particles of a body are communicated to the elastic ether, the transmission would be more rapid the denser the medium; by the theory of emission, according to which luminous particles infinitely minute pass from the source of light to the eye, increased density would retard the light. Practically, the results are the same whatever theory be adopted, since, as Sir John Herschel points out, the extreme difference between the calculations on one or other theory in an extreme case he puts, amounts to $\frac{1}{600000}$ of a second.

273. Transparency and Colour of Atmosphere.—Trusting to the evidence of our senses, we should regard the air as normally pure, just as we are accustomed to consider it as unchanging. But the pure binary mixture of oxygen and nitrogen scarcely exists out of the laboratory. The air may be clear, yet instruments of ordinary delicacy will demonstrate the abundant presence of impurities. Tyndall had great difficulty in procuring optically pure air for his experiments, and only obtained it by sifting out the inorganic and burning the organic particles which floated in it. The sunbeam that traces a line of light from sky to earth demonstrates, by becoming visible, the presence of substances which diffuse the light. Aqueous vapour is present even in the clearest air, so that clearness is not an index of dryness. Absolutely pure air, as obtained in tubes from which all the floating particles have been removed, or as seen in stellar space, is colourless, a dark appearance being due to the absence of anything by which light might be diffused. Great variety of colour is afforded by the play of sunlight on dust and vapour: blue is the most frequent, its cause—vapour—being the most abundant. The purples, reds, and violets of autumn sunsets are doubtless due to the same source; but this whole question of the colours of the sky is one of great difficulty, and is yet far from being decided.

274. Refraction; Absorption.—A ray of light entering air does not travel directly through it: its course becomes bent in such a way that the rays from an object below the horizon, which should pass tangentially to the earth's surface, become deflected and reach the earth. Now, as the eye necessarily estimates the direction of a whole ray from the direction of that last portion of it which enters the eye, as if it were in a straight line from an object above the horizon, the sun, or other luminous body, appears to be above the horizon before or after it is so. The refractive power of the air, water being taken as 1, is ·00058971, both substances being examined at 0° C., and under 29·92 inches of mercury. The amount of refraction depends on the condition of the air as regards density and humidity, being greatest when the air is most humid.

275. Twilight.—To refraction, coupled with the diffusive or reflecting power of the particles in the atmosphere, we owe the phenomena of twilight.



In this figure, which represents a section of the earth seen from the North Pole, R being east, S west, H P is the horizon line of an observer at N: when the sun is above that line the atmospheric segment H A D O receives his direct rays; when the sun declines to M, the direct rays illuminate A D O *m*, but by refraction a part of the atmosphere to the left of the line A C still receives direct light, while the remainder of the space H A C N will receive the light diffused from the aqueous and other particles in the directly illuminated atmosphere. Imagining the sun to be rising in place of setting, the phenomena of dawn are of the same kind. The twilight ends when the sun sinks to 18°, or at the utmost 21° below the horizon; but the afterglow of the clear Nubian atmosphere is a secondary reflection from the diffused light of a twilight; thus, if when the sun is at K, the twilight is bounded by the line A C, the afterglow may be seen along the line H N, or even further to the east.

276. Absorption: Diminution of Light by Distance.— Light travelling through space, and diverging as it proceeds, imparts to successive objects of equal superficial area an amount which is inverse to the square of the distance; thus a surface which receives, at the distance of a yard, a certain amount of light, will receive farther off, at the distance of two yards, a fourth of that amount; at three yards one-ninth, and so on. But this diminution of intensity, which may be accelerated by the intervention of solid or refractive particles, as when mist or dust blocks the way of the light, is entirely different in its results from that absorption by which certain rays are arrested, and cease to give outward signs of their existence. The solar spectrum, which ranges from violet to red, consists, as has been said, of vibrations of unequal lengths. If the yellow flame of common salt is placed in the track of the sunbeam undergoing analysis, the yellow of the spectrum will show dark lines, the absorption bands, which represent the arrest by the sodium flame of those beams to which it gives rise itself: yellow intercepts yellow. A red object appears black in every beam except red. As white light represents the sum of unequal vibrations of the luminiferous ether, absorption means the transfer of the motion of the ether to the particles of a body; but these particles must vibrate in the same time; absorption means, therefore, coincidence of vibrations. It would be beyond the scope of this volume to discuss this subject fully, so that its physiological bearing should be fully explained. But the point which the foregoing remarks may induce the student to investigate for himself is, that as the rays of the solar spectrum have very different influences on vitality, the condition of the atmosphere may from time to time change, and thus exert an influence on organic beings, while the sources of that influence can only be revealed by instrumental investigations.

277. Polarization.—Light which enters any transparent body vertically to its surface, passes directly through; but if it enters obliquely, the parts of the ray are successively retarded, so that the light has an oblique course through the body, emerging at the opposite surface of a body with parallel planes at the same angle which the ray had before entering; emerging at the opposite surface of a triangular prism at an equal and opposite angle to that of entrance. But a body may have its particles so arranged that light passes more readily in one direction than in another. The whole beam is refracted in water as a single beam; but in ice there are two planes of refraction, the one perpendicular, the other parallel to the freezing plane. In ice, and in Iceland spar, there is double refraction, and the light of the twc rays which result from this property has different properties in each ray. The angle of refraction varies for different substances; it is also obviously unequal for the two parts of the same beam in the case of double refraction. The light now consists of two parts, each of which can only be transmitted through another mass of the same substance in exactly the same direction; if the planes are altered, that particular ray is arrested. The same property is conferred by reflection from an ordinary reflecting surface, as of a mirror. In these cases the extraordinary ray, as that one is called which rotates round the ordinary ray as round a fixed point when the spar is made to revolve, is composed of vibrations of the ether, which take place in one plane only. But certain crystals, as of quartz, have the power of making the vibrations move in a circle, and as the component rays of light have different velocities, the result is that a spectrum is formed by the separation of these rays. The details of the mechanism by which these facts are ascertained belong to the domain of Physics. A beam of light, then, falling on a crystal is partly reflected, partly refracted. As the angle of refraction is fixed for every substance, while that of reflection depends upon that of incidence, the beam of light must be shifted from a position perpendicular to the face of the crystal towards one of parallelism, till the plane of reflection is at right angles to the plane of refraction; the angle of the incident beam is then the angle of polarization.

278. Polarization of the Atmosphere.—This angle for air is 45° 0′ 32″. The neutral points are certain spots at which no polarization takes place. Their positions are, "for Arago's point 18° 30′ above the antisolar point when the sun is on the horizon; but if the sun is 11° or 12° above the horizon, and the antisolar consequently as much below it, the neutral point is on the horizon, or 11° or 12° above the antisolar point." After sunset, the maximum distance of the neutral point is 25°. Babinet's point is "as much above the sun as Arago's is above the antisolar point." Brewster's point is between the sun and the horizon. The changes in the polarization of the atmosphere are due to fogs, mist, and ice crystals. The influence of atmospheric moisture is imperfectly known, and the relations of vapour of water still less so; but it is probable that in the determination of these, meteorology will find invaluable aid for those prognostications which are its most important practical application.

279. Transmission of Sound.—By experiment it has been shown that rays of heat, capable of inflaming bodies upon which they are concentrated, may be transmitted through an atmosphere at the freezing point; the ether, whose vibrations are translated into heat, is thus distinct from the atmosphere. But the vibrations of sound are dependent on the existence of atmosphere. The enormous range of the appreciable sounds has already been referred to as extending from 16 to 38,000 vibrations per second. In a previous paragraph (Art. 80), a wave was described as consisting of a condensation and rarefaction; thus the movements of a tuning fork alternately compress and expand the air in contact with it, and these movements are transmitted to other portions of air; but while the pulse is thus propagated, the individual particles of the air move very slightly to and fro. The transmission of the wave takes place in air at the freezing temperature at the rate of 1090 feet per second. But temperature affects the velocity very importantly, as the following table shows, from which it appears that the velocity increases about two feet per second for every 1° of increased temperature:—

Temperature of Air.	Velocity of Sound.
0·5°C.	1089
2·10°	1091
8·5°	1109
12·0°	1113
26·6°	1140

280. Intensity of Sound.—The intensity of a sound depends on the character of the atmosphere in which it originates, not of that through which it travels. A cannon fired on the summit of a high hill may be inaudible in the valley, while, if fired in the valley, it would be distinctly heard on the summit: in the one case the initial intensity is less, the air being rarefied; in the other it is greater, the air being denser. But this does not affect the law of the diminution of intensity, which is, as in the case of light, proportional to the square of the distance.

The rate of transmission of sounds varies in different substances, the variation being determined by the relation of their elasticity to their density. Mertheim found that sound was transmitted by the water of the Seine—

Temperature 15°C., at the rate of 4714 feet per second.
Temperature 30°C., at the rate of 5013 feet per second.
Temperature 60°C., at the rate of 5657 feet per second.

Through gases the rate varies widely, being 858 feet per second for carbonic acid, and 4164 for hydrogen. In solids, the rate varies with the elasticity and the temperature of the body. The following are taken from a table quoted by Tyndall:—

		VELOCITY.	
	at 20°C.	at 100°C.	at 200°C.
Lead,	4,030	3,951	...
Copper,	11,666	10,802	9,690
Steel Wire (English),	15,470	17,201	16,394
Cast Steel,	16,357	16,153	15,709
Iron Wire,	16,130	16,728	...
Iron,	16,822	17,386	15,483

It appears that while increase of temperature diminishes the transmissive power of some metals, as copper, that of iron is increased up to a certain point; and the above table has been quoted for the purpose of suggesting the difficulties in the way of estimating the velocity of subterranean sounds. In an interesting series of experiments on the transmission of sounds through different kinds of rock, Mr. Mallett found that much broken rock impaired the velocity very considerably, and that heterogeneous structure, as of granite, has the same effect. These results are in accordance with the similar fact, that whereas sound travels along the fibre of the wood of a tree at the rate of 15,314 feet, its speed across the rings is only 4567. It is possible, therefore, that the observed velocity of the earthquake noise may be true only for two directions, and that a different conclusion might be drawn from observations made on the progress of the sound at right angles to them.

281. **Sounds more Intense by Night.**—Sounds are more intense, and heard at a greater distance, by night than by day. This is not relative, other sounds being less by night, for, in reality, there is more sound audible than by day, but absolute, the cooler air being more uniform, and permitting more of the sound waves to travel direct.

282. **Refraction of Sound.**—Sound, like light, may be concentrated by a lens, the lens being a spherical mass of air enclosed in a highly elastic substance, as collodion. The divergent vibrations thus made to converge have the effect of rendering sounds audible at a distance by increasing the number of vibrations in a given space.

283. **Reflection of Sound.**—Again, like light, sound may be concentrated by reflection from a concave surface, and the focal length of the sound mirror accurately determined. The phenomena of echoes are illustrations of reflection, the multiplication of the surfaces multiplying the repetitions, as the facets of a prism multiply the reflected images.

284. **Resonance.**—But the reflection of sound from a solid body is distinct from resonance, which is the intensifying of a sound by the synchronous vibrations of a mass of air, which thus multiplies the vibrations, or rather multiplies the points whence they proceed. Echoes proceed from concave surfaces, which may be resonant only to sounds of a particular pitch. It is to resonance that the thunder-like sound of a gun fired in a narrow valley is due, while the sound may be reflected only from one or two points.

285. Transmission of Heat.—Air in contact with a warm body has its temperature raised by conduction or convection. In the former case, the heat radiated from the body, or, in the language of the mechanical theory, the motion of its particles transmitted to those of the air, is passed on through the air by each particle imparting movement to the next. Convection is the transfer of this motion, not by single particles, but by groups of particles: masses of air move upwards, other masses take their place, till the loss of motion by the radiating body is equal to the gain by the air. Equilibrium and rest are then arrived at. But this equilibrium would not exist were the air perfectly dry and perfectly pure; the body would cool by radiation into space; the heat would be thus lost, but the air would receive none of it. The air is therefore in theory neutral to heat rays, it neither absorbs nor radiates. But, as a matter of fact, since it is never pure, it both absorbs and radiates; and, as has been already said, stops 10 per cent. of the terrestrial radiation within 10 feet of the earth. Conduction and convection, therefore, are phenomena of air which is not chemically pure.

286. Reflection of Heat: its Diminution by Distance.—In these two particulars the analogy of heat and light is complete, since the heat or calorific rays may be concentrated by apparatus of the same character as is employed in the case of light; and the ratio of diminution is likewise inverse to the square of the distance.

SECTION II.—ATMOSPHERIC CIRCULATION.

Movements of Atmosphere: Influence of Earth's Rotation—Theories as to the Cause of Currents: Hadley and Maury—Objections—Constant Westerly Current at High Altitudes—Winds of N. Atlantic Basin: N.E. Trades—Mediterranean—Local Winds—Sirocco: Föhn: Analogous Wind in New Zealand—West Winds of N. Atlantic—Calms of Tropic of Cancer—Hurricane Region—Winds of N. America: S.E. Trades—Pacific Ocean—Indian Ocean: Monsoons—Monsoons in other Regions: S. America; Chinese Seas; Western N. and S. America; S. Africa—Course of Atmospheric Currents—Land and Sea Breezes—Velocity of Wind—Storms—Storms of Acceleration—Tornadoes—Rotatory

Storms: Hurricanes, Cyclones, Typhoons, etc. — Velocity of Rotatory Storms: their Area — Storm Waves — Whirlwinds: Waterspouts: Dust Storms—Simoom.

287. Movements of Atmosphere: Influence of Earth's Rotation.—As the air forms a layer round the globe, and as it is practically a fluid, the movement of the globe within this sphere necessarily involves movement likewise of the investing atmosphere. The globe, rotating on its own axis from west to east, and rubbing against the lowest portion of the atmosphere, sets the whole superjacent mass moving in the same direction.

But as the sectional area of the globe diminishes towards the poles, it follows that the movement of the air diminishes in rapidity as we approach the poles. That is to say, the space which the air has to travel at 30° of latitude is less than that which the air at the equator has to travel; thus the air at the 15th parallel of latitude has to travel through 869 miles in an hour, while air at 30° N. lat. passes through 450 miles in the same time. As, therefore, the amount of space to be passed through diminishes as the latitude increases, and as each particle of air has the velocity of the point of earth with which it is in contact, if by any disturbance a particle of air is sent towards the pole, or towards the equator, it lapses, on the one hand into an area of slower, on the other hand into an area of more rapid, movement. Suppose that a particle of air having an eastward movement, at the rate proper to the 45th degree of latitude, is directed towards the pole, it will move eastwards more rapidly than the points of the earth over which it passes, and hence it will appear to have a motion very nearly eastward. If, on the other hand, it moves towards the equator, its rate will be less than that of the regions into which it enters, and it will thus appear to have a westward direction; it lags, so to speak, behind the mass of the earth.

288. Theories regarding the Causes of Currents: Hadley and Maury.—It has been assumed that the two influences under which the circulation of the currents of the atmosphere take place are heat and the rotation of the earth, heat being the primary originator of its currents; and Hadley's theory asserts, (1) that the trade winds which move from the poles towards the equator, and the counter trades which move from the equator towards the poles, are due to the relatively high temperature of equatorial regions as compared with that of polar regions; (2) that the westward tendency of the trades, and the eastward direction of the counter trades, are due to the rotation of the earth. This is the commonly asserted doctrine, and in accordance with it the course of currents in the atmosphere is stated to be after the following order:— 1. The over-heated air at the equator rises vertically into the atmosphere, and spreads itself towards either pole, while the colder, and therefore heavier, air from the north travels towards the equator to take its place. 2. The upper stratum of air, when it reaches about the 35th parallel of latitude, has parted with its excess of heat, and descends towards the surface of the earth. 3. Part returns again towards the equator, and part passes on towards the pole, forming the south-westerly winds of high latitudes. Maury further imagines that the air, having again reached the equator, becomes heated, but does not part with its onward movement, and, in fact, continues its progress across the line to one or other pole, as the case may be, whence it again returns in the same undulating line and completes the surface of the globe, the currents thus pictured forming a series of figures of eight, the nodes of which, or the points where the currents meet the surface of the earth, constituting the three bands of calms—the equatorial, and those of Cancer and Capricorn.

289. Objections to these Views.—Several objections must be taken to this view: in the first place, the regions of calms and variable winds do not form continuous zones all round the earth; they are like the dead waters of the Sargasso Sea in the Atlantic, and of its counterpart in other oceans, limited in dimensions, and do not touch the land on either side. In the second place, if excess of heat were the determining cause of the atmospheric movements, the north-easterly trades of the Atlantic would be converted into west winds blowing across the continent of Africa, since the interior of that continent has a temperature at times 27° higher than that over the Atlantic; for while air in contact with the sea at the equator seldom exceeds 27·7° C. (82° F.), as much as 54·4° C. (130° F.) has been recorded in the interior of Africa. Again, westerly winds blow in the polar regions both in winter and in summer, although at the one season the ocean area, at the other the land area, is the warmer. Neither can the rotation of the earth be admitted to influence to any great degree the movements of the air currents; because we find that the air actually travels from north-west to south-east, or from south-east to north west in the northern hemisphere; and from south-west, or from north-east, in the southern hemisphere, beyond the 45th parallel, although these directions are contrary to what should take place according to theory, being polar not equatorial; and it is certain that the air acquires directly the motion of the earth at the point with which it comes in contact. It seems more probable that the movements of the atmosphere are, as a whole, from west to east, and that the variations from this dominant direction are local in their origin, and are the counterpart of the movements which take place in the ocean.

290. Constant Westerly Current at High Altitudes.—It has been frequently observed that ashes from tropical volcanoes travel to windward, contrary to the direction of the steady easterly and north-easterly winds, and that they have been thus transported for hundreds of miles. Frequent observations have been recorded of the upper clouds travelling eastwards, contrary to the movements of the lower strata; and the observations of many travellers coincide with those of Professor Smyth on Teneriffe, to the effect that strong westerly winds prevail at high altitudes, while easterly winds are travelling along the surface of the earth. So far, therefore, as these observations go, there seems no reason for doubting that the upper current has a westerly movement in high altitudes, and that that movement is for the most part a very rapid one. In the higher latitudes, both north and south, westerly winds prevail, and these are subject, as they approach lower latitudes, to various deflections, which are the counterpart of those observed in the case of the easterly drift of the Antarctic Ocean.

291. Winds of the Atlantic Basin: N.E. Trades.—For the most convenient description of the various winds which predominate at different points of the earth's surface, it will be best to follow the same geographical arrangement as was adopted in the case of the ocean circulation. In the North Atlantic, between 10° and 25° N. lat., the north-east trade prevails, the belt thus limited advancing towards or receding from the equator according to the seasons, being nearest to the equator in January, farthest from it in July. Between 15° and 20° the trades blow steadily throughout the year; and this fact is recognised by navigators, who know this region as the heart of the trades. Towards the northern limit of this belt the currents have a more northerly direction, and towards the American side the westward direction is more conspicuous, this variation being due to the influence of rotation. The winds, however, upon the African shores are deflected at Cape Verde, and become north-west winds, passing southwards towards the Gulf of Guinea. On the African continent, easterly and north-easterly winds prevail; and under their influence the sand storms of the desert are carried out seawards, the red dust being frequently deposited upon ships at considerable distance from land. Harmattan is the local name of the north-east wind blowing seawards from the Sahara to the south of Cape Verde in the winter months, especially January and February. The conversion of the trades into easterly winds, towards the West Indian Islands, renders them important auxiliaries of the equatorial current, which sets towards the Gulf of Mexico. On the east side of the Atlantic, beyond the limit of the trades, northerly winds, chiefly north-west, though sometimes also north-east, prevail, and influence navigation importantly, since homeward-bound vessels, returning from Spain, are obliged to go 20° to the west before they can turn northwards, though the outward voyage is facilitated by them.

292. Mediterranean.—The dominant direction of the Mediterranean winds is from the north. Local names are given to particular winds: thus, the north-west wind of the Gulf of Lyons and West Italy is known as the Mistral; the north wind of the Adriatic is the Bora; the Gregale is the north-east wind which strikes Malta; and the Archipelago is visited by the Etesians, or north-east winds of summer; while the Tramontana is the winter wind of that region. In the Levant the summer wind is from the north-east, that of spring from the north-west; and along the north coast of Africa the easterly wind known as a Levanter is tolerably steady. The Sirocco is a remarkable exception both to the direction and the character of these Mediterranean winds. It travels from the south-east, carrying with it the red sand of the desert, and, crossing Malta and Sicily, strikes upon Italy, producing there very remarkable physical and physiological effects. It is hot and damp; the temperature rises as high as 35° C., and its severely depressing effects are manifest both on animal and vegetable life. Its character is consequent upon the elevation of the Sahara into dry land, and there is every reason to believe that to its influence may be traced the shrinking of the Italian glaciers upon the southern slopes of the Alps. It has been calculated that if the Sahara were again laid under water, the plains of Lombardy would cease to be the richly productive regions we now see them.

293. Causes of Sirocco: Föhn.—The sirocco crosses the Alps and becomes the föhn, or south-west wind of Switzerland. But it has entirely changed its character; and as the history of this current illustrates several important points, it deserves some attention, more especially as it is even yet a subject of discussion among meteorologists. The N.E. trades in the Atlantic recede northwards during summer, and the coast winds of Africa are at that season frequently from the west. The north-east winds of the continent are thus impeded in their seaward progress, even blown back, and forced to find an escape to the north as the sirocco over Italy, the solano in Spain. The sirocco blows at all periods of the year, but most frequently in spring and autumn; and at these periods the African interior receives supplies of air, warm and moist, from both coasts, from the Gulf of Guinea, and from the Red Sea, as well as from the Mediterranean. It thus starts with a considerable quantity of moisture, which is increased as its over-heated lower strata pass over the sea. Precipitation takes place in the north of Italy: the wind, however, goes on, rises over the Alps, and, cooled during expansion, regains a higher temperature on the low grounds to the north, where it resumes its former density. But the temperature is not quite so high, since the vapour which it still carried over the heights would permit radiation into space, and this heat would not be regained by renewed density.

294. Transmontane Wind in New Zealand.—The phenomena attending its passage over the Alps are exactly parallel to those observed in New Zealand, where a north-west wind throws down rain or snow on the coast and hill face on which it strikes, though this is not always the case, as the precipitation sometimes takes place before the land is reached. On the south-west face of the range, the wind descends the valleys with heat sufficient to cause floods in the glacier streams by the sudden melting of the ice.

In the northern part of the Atlantic basin, north that is to say of 35°, west winds prevail, and the "Roaring Forties," about 40° N. lat., are tolerably steady in their direction, though in winter they reach the British coasts often with very great violence. The years of greatest loss, by shipwrecks, on the west shores of the British islands are those in which these westerly winds have attained their greatest violence. It may be said that generally west winds prevail over Europe, and reach as far as the Black Sea, to the south of which the northern tendency reappears.

295. Calms of the Tropic of Cancer.—Over an area generally similar to that of the Sargasso Sea, to the north, that is to say, of the trades, in 30° to 35° W. lon., there is a variable region known to sailors as the Horse Latitudes, which lies in an area bounded by northerly winds on the east and west; by the west winds to the north; by the trades to the south. The winds in this region may come from any point; they may blow with great violence, or may be succeeded by calms. This change in the character of the winds increases the analogy to the Sargasso Sea, whose shifting position is due to the encroachment of one or another current.

296. Hurricane Region.—The hurricane district of the West Indies comprises the islands from Barbadoes north-westward, even to Mexico, and north-eastwards to about 70° W. lon., and there is reason to believe that their influence is felt indirectly upon the shores of Europe. The general track of the hurricanes is from a point to the east of Barbadoes, in 10° to 15° N. lat., thence to the west north-west as far as Florida, and northward to about 40° N. lat., where they die out. They are sometimes continued westwards into the Gulf of Mexico, but never affect the continent beyond the Alleghanies.

297. North American Winds.—The continent consists of a central valley lying between the Rocky Mountains and the coast ranges, but open to north and south. The Rocky Mountains cut off well-nigh entirely the westerly winds, and a northerly direction prevails in the central trough as far as about 35° N. lat.; south of that the direction is unceasingly from the south-west, though south-east is frequent at the foot of the Rocky Mountains, the wind following the curve of the high ground. The winter winds are chiefly from the north-west, a direction observed even in the Caribbean Sea. These cold winds, which blow down the whole American valley, become more and more westerly among the islands, whence they pass to rejoin the westerly winds of the North Atlantic. They are the northers of the Mexican Gulf, the counterpart of which exists on the homomorphic western coasts of the Pacific.

298. South-east Trades.—The south-east trades are very steady, and in general stronger than the north-east. They occupy a belt, likewise variable in position, between 0° and 25° S. lat.; in winter they reach 5° N. lat. On the African coast they are more southerly in direction, and in the Gulf of Guinea westerly winds prevail, the direction shifting from west north-west to west south-west, and calms are of frequent occurrence. This region of variable wind extends as far as 3° W. lon., and the names by which it is known are: Region of Equatorial Calms, Region of Variable Calms, Region of Variable Winds and Calms, Region of Constant Precipitation, Doldrums, or the Rains of earlier navigators. This region, in fact, corresponds generally with the triangle left between the two roots of the equatorial ocean current, and is thus an atmospheric dead-water, in which west winds struggle for predominance. To the north and south of it the trades sometimes coalesce into an east wind, blowing towards the Caribbean Sea. On the opposite sides of the S. Atlantic basin, opposite tendencies exist, the northerly prevailing on the American shore, the southerly prevailing on the African side, though these are converted into west winds during winter. On the southern continent of Africa, as on the northern, the trades are, as a rule, distinctly felt. On the American continent considerable variations, however, exist; thus, the trade passes up the Amazon valley as an east wind, which from July to January—the dry season—blows with increasing strength; but in the wet season dies down almost to the coast line. In Paraguay north-east winds prevail, north-west being rare. But the pamperos, farther to the south, are north-west, west, or south-west winds, which blow across the pampas, often with great and sudden violence. From 40° S. lat. the westerly circumpolar winds prevail as steady and strong currents which, near Cape Horn, form westerly or south-westerly gales. Another region of calms exists between 0° and 15° W. lon., 27° and 37° S. lat., and represents an ellipse whose position is variable, and whose long axis is from north-west to south-east.

299. Pacific Ocean.—The Pacific Ocean manifests the same westerly currents in high latitudes as does the Atlantic. The north-east trades form a belt between 0° and 20° N. lat. The south-east trades range from 0° to 25° S. lat. The north trades are not so steady as those of the Atlantic, and both they and the south trades have a more easterly direction. The north-east trade, striking upon the Philippine Islands, acquires a southerly direction, thus following to some extent the course of the Japan current. In the north China seas the winds undergo seasonal changes, being south-west in summer, and north-east from November to April; and, to complete the resemblance which this region presents to the corresponding portion of the American continent, we have hurricane regions in which typhoons occur between August and October, their position being from 10° to 23° N. lat. To the seasonal variations the term monsoon is applied, although the phrase is more strictly applicable to the variable winds of the Indian Ocean. As in the latter region, the south-west monsoon is the wet summer wind, the north-east is the dry wind of winter. On the American side, the trade winds go farther to the north, and have, as on the corresponding shores of Africa, a more northerly direction, even acquiring a north-westerly inclination. On the Mexican coast, the winter winds are north or north-west, the summer south-west or south-east, but across the open ocean westerly winds prevail above 40° of latitude; and between this region and the shifting limits of the trades, a variable region exists, which does not, however, reach the land upon either side. In the southern Pacific Ocean, the south trade loses strength westward, and among the islands is replaced by irregular westerly winds. On the Chilian coast, monsoons vary from south and south-west in summer to north, commencing in March; and here, as in many other cases, the polar wind is dry, the equatorial moist. But, on the Peruvian coast, the summer wind is south-west and moist, though heavy fogs accompany the rare north winds. In winter, the north wind blows from the Caribbean Sea as a papagayo or tehuantepecer.

300. Indian Ocean.—The winds to the north of 12° S. lat. in the Indian Ocean, are alternately from north-east and south-west, and are hence known as monsoons, though that term is originally applied only to the alternating winds on the Arabian coast. The south-east trade blows in winter to the equator; but, in summer, its northern limit retreats to 12° S. lat. In winter, it is more and more easterly towards the equator; but, in summer, the area of 12° which it has deserted, is traversed by winds from the west, north-west, or south-west. The trade shifts its southern limit also, and thus the variable region, the calms of Capricorn, which separates it from the constant Antarctic west winds, is carried up and down. This region is only a patch separated from Australia by the winds which blow northwards to feed the trade, while the African winds again limit to the west. We have here another example of an atmospheric backwater, in which the westerly winds struggle to prevail, and the weather is thus very irregular and broken.

Summer and winter are those of the north and south hemispheres respectively.

301. Monsoons.—It is impossible, within the compass of this chapter, to make clear the great irregularity of the movements which are comprised under the one phrase, monsoons. It is usual to state their character summarily, as that of a wind which, from May to September, blows from the south-west; and from October to April, from the north-east. But this is only true for a few localities, as the coast of Arabia. It may be said, in general terms, that the winds north of the equator, from October to April, are northerly, chiefly from the east of north, but even from the west of north; and that the winds from May to September are more markedly westerly in the open sea. The deflections may be grouped according to the coast lines. Thus the parallel lines, from Calcutta south-eastwards and from Cutch to Cape Comorin, from Calcutta to Ceylon and the west side of the Indian Ocean, show parallel movements of the winds. On the Malabar and Burmah coasts, the N.E. monsoon, which at sea is steady, blows from north-west; the S.W. monsoon is from the west, or north of west, on the Malabar coast; it blows north-west past Point de Galle, and returns as a south-easter to the Coromandel coast, though it is more strictly south in the open sea; and again south-west when it blows inland at the north end of the bay. The Red Sea, during the N.E. monsoon, *i.e.*, from October to April, is traversed by a south-east wind; and from May to September, by a north-west. Some of the summer variations are tabulated below.

N.W.,	Gulf of Oman.
S.W.; S.S.W.,	S.E. Coast of Arabia.
N.; N.E.,	Red Sea.
W.; S.W.; S.E.,	Bay of Bengal (west and north).
W.; N.,	Bay of Bengal (east coast).
W.; W.N.W.,	Malabar Coast.
N.W.; W.N.W.,	Cape Comorin.
N.W.,	Nilgherries.
S.W.; W.; N.W.,	Off Hooghly.

The similarity of the movements on parallel coast lines, and the remarkable variations in the Red Sea, indicate the power of local geographical conditions as superior to any general influence, such as rotation of the earth.

To the south of the equator, the south-east trade is only variable in position, is not reversed in direction by the seasons; this is true at least for the area from 12° to 25° S. lat. The seasonal reversal between 0° and 12°, gives during winter the eastward movement, which may be regarded as the extreme deflection of the south-east trade; while in summer a westerly wind traverses the ocean, and passes into the Pacific through the island channels. This westerly wind, the N.W. monsoon of the South Indian Ocean, is more northerly near Madagascar, and even may blow from the east of north. The influence of local features is again illustrated in the winds of the Mozambique Channel, which blow during winter from the south-west, during summer from the north-east. Now, as the wind blows along the coast of Africa from the mouth of the Arabian Gulf as a north-east wind during the months October to April, and as in summer the S.E. trade retreats to 12° S. lat., the Mozambique wind of that season is a prolongation of the N.E. monsoon of the North Indian Ocean, while the winter wind is the deflection of the S.E. trade, which at that season blows to the equator.

302. Monsoons in other Regions.—The word monsoon is now used for alternating winds in other regions; and as this custom is becoming popular, it would, perhaps, be well to use the term, in books on Physical Geography, for any winds at any locality whose direction shifts with the seasons, and which divide the year, however unequally, between them.

Using the term, then, in this wider sense, we have monsoons in the China seas, in the Mexican Gulf, on the coasts of Africa, and South America.

303. S. American Monsoons.—The N.E. trade reaches the north-east of South America, north of the equator, from December to April; but, for the rest of the year, the vendabales, wet westerly or south-westerly winds, alternate with south-easterly winds along the coast. There is here repeated, and for exactly the same reason, what happens on the east coast of Africa in the Mozambique Channel. The northern summer carries the trades to the north, and the S.E. trade blows into the Caribbean Sea, while the southern summer brings the N.E. trade nearer the equator. In the Gulf of Mexico itself an alternation of the same kind is seen, but its periods are not sharply defined; and the north winds come down the Mississippi valley, their movements having reference to other influences.

304. Chinese Monsoons.—From October to April, the Formosan winds are steady at north-east; and, like the polar winds on the American side of the Pacific, they are dry and clear. For the rest of the year, with the exception of the typhoon months, the wind is from the south-west, and is even more southerly at the Philippine Islands. These regular seasonal alternations extend, there is every reason to believe, into the interior, the floods of the Yang-tse-Kiang not being explicable by the melting of snow, which does not lie on the Thibetan high grounds; so that a wet season, that of the southerly or south-westerly monsoon, is the only other source of the excessive moisture.

305. Monsoons of Western N. America.—From June till October, or rarely November, the winds are, on the west coast of Mexico, from south, south-west, or south-east, and are wet, as equatorial winds are for the most part. In winter, over the same area, north-westerly winds prevail, and may reach even to the equator, if they pass their customary limit about 10° N. lat.

306. Monsoon of Western S. America and S. Africa.—The north-west winds, with much moisture, increase in their duration as we advance southwards on the American coast, till in Patagonia westerly winds occupy most part of the year; but these are derived from the westerly winds of high latitude, and the alternate preponderance of the northern or southern element is recognisable. But the winds on the American continent have at once greater obstacles to encounter in the mountain chains, and greater freedom of escape over the open Pacific. Hence their movements have much less of periodicity than where, as in the Indian Ocean, the space is more restricted. In the South Atlantic, the African coast is lower than that of America, while the great projection of the northern portion acts more effectually than the similar prominence of western North America, in checking the movements of the air and forcing the currents more into the interior. Hence the African coast is characterised chiefly by the frequency of its calms.

307. Course of Atmospheric Currents.—There are two starting points from which to trace the winds. According to the common notion, the starting point is the trades, which are the indraught of cooler air to replace the warmer air which ascends over the thermal equator, or line of greatest heat. This in July reaches as far as 10° north of the equator, and in January to 2° or 3° south of the equator. The ascending current over this region, then, is the starting point, whether *or not* the existence of those undulations already referred to (Art. 288) is believed in. But, on the other hand, the region of a steady westerly wind seems a much more reliable area to start from, than one in which, so far from a vertical circulation being proved, easterly and westerly winds struggle, and calms frequently indicate the absence of all motion, while excessive rainfalls likewise tell of arrested motion in the air. Starting, then, with the westerly current as consequent on the rotation of the earth, we find that it strikes the level of the sea at 40° lat. N. and S. Its progress eastward is arrested by the shores of the Atlantic and Pacific. But these present very unequal obstacles. The mountain backbone of America is low only in the centre. To the north and south it stops almost entirely every direct influence from the west. The eastern shores of the Atlantic, on the other hand, consist chiefly of low grounds, or of chains which run from east to west, and thus present less powerful obstacles to the progress of the current. The wind passing over Europe is deflected by the central mountain chains through gaps in which the mistral, the bora, and other north-westerly currents pass, while the Ourals and the colder, denser air of north and central Asia check its eastward progress, the eastern and western direction of the great ranges permitting its free passage as far as the western rampart of the Thibetan plateau. From Hayward's explorations, it appears that the winds of eastern Turkestan are dominantly from the west, and that there are passes through which these winds enter the country to the north of the Himalayas. But to the south of the sources of the Kashgar river, a mountain range, with peaks of upwards of 21,000 feet in height, forms a wall which reaches the Hindu Kush, and thus gives that southerly direction which Burnes records as prevalent in Bokhara. Thence it may be followed to the south-east, till it enters the low ground south of the Himalayas, and descends the main valleys of the Ganges and Indus. Its eastward direction is resumed on the east sides of the Indian Ocean, but it divides on the north-east corner of Africa, part turns south-westwards with the African coast, while the other part follows the hollow of the Red Sea. The S.W. monsoon corresponds in time with the easterly monsoon which blows south of the equator. But when the north-westerly monsoon, or more strictly the westerly monsoon, blows in the summer of the south hemisphere, the N.E. monsoon is blowing in the north; the two winds, therefore, intervening between the N.E. monsoon and the S.E. trade, are in reality different phases of the same westerly wind, which in the narrower Atlantic fails to attain the same fetch, and thus blows with less strength in the open ocean; in the Indian Ocean, moreover, it has an escape through the insular channels. The N.E. monsoon is in position the equivalent of the N.E. trade, and thus comparing this with the two great oceans, the equatorial calm and variable region is here greatly enlarged, swinging alternately to the north and south of the equator through a greater range.

The deflections of the trades have still to be accounted for. If there is no *continuous* range of mountains across Africa, there seems some obstacle sufficient to prevent the European winds passing south, and to force them westwards to join the trades, which, however, start farther north than this source of supply. The air over the land is appealed to as, in defect of other more powerful barricades, sufficient to deflect a current. It would appear as if the equatorial belt of westerly winds and calms presented such a case; the trades acquire increased easting as they approach the equator, and the belt shifts with them to north and south. As that belt is one of low barometeric pressure, it must be only difference in quality of atmosphere which prevents its being torn away and absorbed into the trades on either side; the contrary takes place in the west of the Atlantic and Pacific oceans, where the trades contribute to the westerly winds which sometimes blow in the equatorial calm region.

The order here indicated is founded on theoretical considerations, which have not yet met with entire acceptance. Into the arguments in support of the arrangement it is impossible here to enter. The student will find them discussed in Laughton's work already referred to, and in various communications in journals. It is only necessary to say further, that, while the primary motion is ascribed to a westerly current, and the great majority of the phenomena are easily *strung on this* theoretical thread, the auxiliary influence, under certain circumstances, of pressure, and difference of temperature, is by no means excluded.

308. Land and Sea Breezes.—Thus the alternate movement of air to and from the land, by day and night, seems due to the combined influence of increased pressure and difference of temperature. The air over the sea receives, as the heat increases, a large amount of vapour by evaporation, and thus acquires greater elasticity than that over the land, upon which it thrusts itself. During the night, when evaporation is checked over the sea, the air, cooled down by radiation and by diffusion, loses more elasticity than that of the land, which thrusts itself out seaward. A certain approach to equilibrium between the sea and land air, however, is needed; thus these breezes are not known where the shores are bare of vegetation, and the temperature of day and night are thus very different. The east wind of night on the Tapajos as observed by Bates to replace the west wind, doubtless comes from the interior, and thus gives a transition from the diurnal variation to a seasonal variation, of which many examples occur in the monsoon area on a small scale.

It is again, as in the case of ocean currents, defective knowledge or extreme statements which give rise to controversy; and as there is still uncertainty as to the machinery of atmospheric circulation, that view has been here adopted which gives greatest coherence and simplicity to the subject. The student must bear in mind that it is a question of how much influence each agent may fairly be credited with, and upon these amounts the most conflicting statements are made.

309. Velocity of Wind.—The same necessity for reference to a fixed standard exists in the case of wind, as of heat and light; perhaps even greater, since the circumstances under which excitement is likely to make the unaided senses worthless guides, are those against which it is most important to guard, by learning most accurately every detail of their occurrence. Wind gauges of various kinds are used, and these of course give sure results. But in defect of these, it is necessary to have a scale commonly intelligible, by reference to which the risks of error are diminished. The Beaufort scale recognises thirteen grades of movement, which are determined by reference to the speed of a ship or the sails she can safely carry. But it is more common to use a scale of seven grades, 0—6, between which the intermediate steps are marked ·5. The formulæ for calculating the velocity V, and pressure P, are $P = V^2 \times \cdot 005$; and $V = \sqrt{200 \times P}$. The pressures and velocity are given in the following table, which is copied from Buchan, p. 211.

Scale 0—6	Pressure. lbs. per sq. foot.	Velocity. miles per hour.	Beaufort's Scale.,		
0·0	0·00	0·0	0	Calm, ...	Just sufficient to make steerage way.
0·5	0·25	7·1	1	Light air, . . .	
1·0	1·00	14·1	2	Light breeze, .	With which a ship with all sail set would go in smooth water. 1-2 kts.
1·5	2·25	21·2	3	Gentle breeze, .	3-4 „
2·0	4·00	28·3	4	Moderate breeze,	5-6 „
2·5	6·25	35·4	5	Fresh breeze, .	In which she could just carry Royals, etc.
3·0	9·00	42·4	6	Strong breeze, .	Single reefs and T.G. sails.
3·5	12·25	49·5	7	Moderate gale, .	Dble. reefs, jib, &c.
4·0	16·00	56·6	8	Fresh gale, . .	Triple reefs, etc.
4·5	20·25	63·6	9	Strong gale, . .	Close rfs. & courses
5·0	25·00	70·7	10	Whole gale, . .	In which she could just bear close-reefed maintopsail and reefed foresail.
5·5	30·25	77·8	11	Storm, ...	Under storm staysails or trysails.
6·0	36·00	84·8	12	Hurricane, . .	Bare poles.

But while, as has been said, the estimated force may be exaggerated, the instrumental observation is liable to error, both of excess and defect. In every gale gusts may, for a few minutes, give a pressure of 80, though the storm is far short of a hurricane; and, on the other hand, the instruments do not fully record the suddenness which constitutes the chief dangers of the revolving storm to sailing ships.

310. Storms.—Though it may not be easy to say at what point a storm begins in temperate regions, where the acceleration of the wind is often gradual, the tropical storms are abrupt enough to mark them sharply off from the ordinary states of the atmosphere. Their suddenness gives them a distinct character apart from their rotation, but does not afford a basis of classification. We may, perhaps, regard storms as belonging to two groups.

1. Those which are accelerations of the prevailing winds, whether caused by increase of pressure from behind, or by diminished pressure in front.

2. Those in which the prevailing direction is altered.

311. Storms of Acceleration.—The hot winds, the sirocco and simoom, both southerly, both coming from heated sandy deserts, are perhaps the best examples of winds driven by pressure from behind. The gales of the N. Atlantic, of the Patagonian coast, and of other localities where the prevailing wind comes in contact with a current of different temperature and different elastic tension, are due to the sudden diminution of pressure by condensation, which is propagated backwards in one or other current by the steady advance of that which has after the contact the greater amount of tension.

312. Tornadoes.—The harmattan has already been described (Art. 291); but it remains to add that the southward shifting of the thermal equator has probably to do with the occasional acceleration of this wind, by the amount of sudden precipitation which takes place. This certainly seems to be the case with the tornadoes of West Africa, in which the barometer and the direction of the wind are unchanged during the height of the storm.

313. Rotatory Storms.—But difficult as it is to trace the origin of storms whose direction is rectilinear, perplexing as is the effort to fix the relative importance of barometric variations, it is still more difficult to accept, as conclusive, any of the explanations hitherto given of the rotatory storms. The meeting of antagonistic air currents, differences of electric tension, rotation of the earth on its axis, as well as variations of atmospheric pressure, have been appealed to. The facts seem to be:—1. That the hurricanes of the West Indies, the cyclones of the Indian Ocean, the Chinese typhoon, start from the areas in which currents mingle from different directions. 2. The rotation is, in the West Indies, N.W.S.E., with the sun; in the South Indian Ocean N.E.S.W., against the sun, but with the hands of a watch. 3. That the centre of the revolving mass is an area of low pressure, two inches lower than outside. 4. That the track of the spiral follows the course of the prevailing wind. 5. That the barometer falls before the storm. 6. That heavy rainfall, and frequently electric displays, accompany the storm. 7. That when the storm approaches and touches the shore, a storm-wave is hurled on the land with terrible effects. The unsettled questions in meterology are: Is the barometric depression before the arrival of the storm the cause, or is it an effect like the wave which precedes a swift steamer? is the rainfall a cause here of movements which in other tropical localities it does not cause?

The months in which these storms occur are given below, the West Indian figures being a mean of several years; those for the cyclones the statistics of one year; while for the typhoons the months of greatest frequency are merely marked with a star.

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jly.	Aug.	Sep.	Oct.	Nov.	Dec.
West Indies,	1·5	2	3	2	1·5	3	7	28·5	24	20·5	5	2
S. Indian Ocean,	10	16	17	10							1	3
Typhoon,								*	*	*		

The track of the hurricane has already been described (Art. 296). It practically starts along the oblique line formed by the northward passage of the S.E. trade. Its parallelism to the course of the Gulf Stream seems to indicate that both are directed in their movements by the trend of the coast-line as soon as they are clear of the Mexican Gulf. But when a portion of the storm enters the gulf, it there also follows the coast line and sweeps round the shores.

The origin, course, and period of the typhoons are singularly repetitive of those of the hurricane. Their range in latitude is from 10° to 24°.

The cyclones are on the northern limit of the S.E. trade, as it recedes southwards, followed by the N.W. monsoon. They start far to the east, near to Java, and travel along the margin of the trade, bending towards the south-west near Mauritius, the N.W. monsoon there blowing farther south than elsewhere, just as the S.E. trade in the Atlantic reaches far towards Barbadoes.

In the North Indian Ocean they start near to the Nicobar Islands, and reach to Calcutta or to Madras, for their course varies in different years. They are less frequent to the west of the Indian peninsula, along whose shores they commonly travel.

These are the principal areas in which revolving storms occur as regular periodic events. But in temperate regions cyclonic storms sometimes are observed, and of these barometric variations are probably the efficient causes.

The *Storm Chart* of Europe for November 2, 1863, given by Buchan, page 242, illustrates the relation of the strongest winds to the area of minimum barometric pressure, 28·9 (that of Europe being on the average 29·9). The track of the two storms was from the west of Ireland to the head of the Gulf of Finland on the one hand, through Denmark towards Riga on the other. As the former of these is the more common for the European storms, and as it is from S.W. towards N.E., it is again an example of the prevailing winds fixing the course, whatever may have been the origin of the movement.

314. Velocity of Rotatory Storms.—Two distinct velocities must be kept apart; that of the wind, which may attain to 100 miles an hour, shifting round the compass, and that of the storm which travels at from 10 to 15 miles an hour—though the hurricane of 1866 is said to have approached Bermuda at 30 miles an hour. The storms of Europe travel at rates varying from 15 to 45 miles an hour, 18 miles being the most common rate; and it is worthy of note that those which occur in the area of westerly winds, are more rapid than those of the trade return currents. The determination of velocity is of importance with reference to the transmission of storm warnings.

315. Area of a Rotatory Storm.—The diameter of the revolution is variously stated. Many are known to have had a diameter of 50 miles: 100 miles is proved to have been the diameter of one. But the extreme breadth assigned, 1500 miles in some cases, requires strong proof. Buchan's chart, already referred to, shows that the proximity of two distinct storms might have led to their reference to one had the intervening points not been observed; and apart from this, the observations on which such wide limits are asserted would require to have been made simultaneously.

316. Storm Waves.—The centre of a storm is an area of low barometer; but this is not due to centrifugal force, for it is certain that the movement of the wind is in reality vorticose. Precipitation in the centre of conflicting winds gives rise to vortex movement, just as water escaping through a hole entails secondary whirls in the air above it. This sometimes takes place in the tornadoes, and in the gales formed, as at the mouth of the La Plata, between the sea and the river winds. The consequence of precipitation is diminution of elasticity; thereafter the vorticose movement increases in strength, and rises as air is drawn in along the ground, for in all these cases the wind is not parallel to the ground, but strikes down and is reflected from it. The centre is thus a cup with the mouth downwards, into which the water is raised; and when an obstacle occurs, when the cup is broken, the water, no longer supported, "holds its way," and is thrown down in mass over the land.

317. Whirlwinds: Waterspouts.—Every gusty day one may see eddies round corners, which illustrate the principles laid down as to the movement of wind and water when they come against an obstacle. But the phenomena which have now to be considered are of another kind. They are in temperate regions usually connected with electric disturbance. These local rotatory storms are sometimes called tornadoes; and etymologically the name is better applied than to the usually rectilinear gales of West Africa. The account of that of Chatenay, near Paris, in 1839, quoted by Noad, describes what is sometimes seen on a small scale on the high grounds of north Scotland; the lower part of a thunder-cloud swelled downwards and became a conductor between the upper clouds and the earth. The inverted cone became surrounded by dust and light objects, drawn up to and wheeling round it; the now continuous pillar travelled forward for some time, uprooting and twisting everything in its way, and finally, the upper half was withdrawn into the clouds, while the base of the pillar sank, a mass of rubbish, to the earth. A similar description is given of the waterspouts whose formation has been observed in the Pacific; and it is interesting to note that the descent of the cloud-funnel to meet the ascending cone of water was preceded by veering winds, in the axis of which the spout was formed. Palgrave describes deep circular hollows in the Arabian desert which were probably formed by such whirlwinds, and in the Australian deserts similar appearances have been detected.

318. Dust Storms: Simoom.—The dust storms of India consist of a number of whirlwind columns moving together; those of Nubia, described by Baker, move independently, as do those of the Sahara. The phenomenon may be imitated by the ascent of a number of adjacent columns of smoke from smouldering cotton, the spirals of each pillar and of the whole mass being distinct if the air is still.

The simooms of the Arabian desert, and the samiel farther to the east, seem to belong to this group; they certainly differ from the sirocco, inasmuch as their origin is within the limits of the desert, and local heating of the surface seems the only adequate explanation of their origin.

SECTION III.—ELECTRICITY AND MAGNETISM.

Terrestrial Magnetism—Magnetic Equator—Line of no Variation—Annual and Daily Variations—Intensity—Magnetic Storms—Aurora Borealis: Cause of its Light—Atmospheric Electricity—Diurnal and Annual Changes—Relation of Electricity to Heat: Conductors—Conditions affecting the Amount of Electricity in the Air—Thunderstorms.

319. Terrestrial Magnetism.—The magnetic needle, when suspended horizontally, does not point to the north pole of the earth, but at Greenwich points between 20° and 21° west of north. This, the north magnetic pole, has its counterpart in an antarctic pole, which is correspondingly east of the earth's pole. This variation of the needle is not constant. The pole has shifted since A.D. 1576 from 11° 15′ E. to due north in 1657, thence to its westward maximum, 24° 27′ 18″ in 1815, from which it is now moving back.

But the change has not been in one plane. If a needle is suspended so that it can swing vertically, it will not remain horizontal, but its north pole will be deflected downwards at an angle of about 68° to the horizon at Greenwich. The nearer to the magnetic pole the greater will be the deflection, so that at the pole it should be vertical. The deflection diminishes towards the magnetic equator, and again increases in the opposite direction in the southern hemisphere. Now this dip of the needle has diminished, at London, from 74° 42′ in 1720, to 68° 2′, and this indicates a greater distance from the pole now than formerly. Taken in connection with the variation from east to west, the magnetic pole seems to have described a circle round the terrestrial pole from east to west, and Mr. R. A. Proctor assigns about 650 years as the period of the complete revolution.

The earth is thus a magnetic mass which affects the needle as any other magnetic mass would; and the student can repeat the main features of the phenomena with a magnetic bar suspended in a paper globe, while a needle is carried to and fro outside.

320. Magnetic Equator.—Latitudinal bands have been described round the globe, passing through the points of equal dip. The equator, or line of no dip, is north of the equator between the meridian of Greenwich and 180° W. lon., south of the equator for the rest of the globe's circumference.

321. Line of no Variation.—This line, though not regarded as of great importance, is of some interest. From the magnetic pole it passes to the west of Hudson's Bay, thence south-east outside of the Antilles, crosses the eastern prominence of South America to the south magnetic pole; thence crossing the western portion of Australia, it reaches the terrestrial equator in about 75° E. lon., and passes northward to the magnetic pole.

322. Annual Variations.—Between the vernal equinox and the summer solstice, that is, from April to July, the westward variation diminishes; for the rest of the year it returns westward.

323. Daily Variations.—The needle moves alternately eastward and westward towards the sun, whether he is above or below the horizon: the maximum of the easterly movement is reached at 7 A.M., the maximum westerly movement at 1h. 10m. P.M., whence it recedes eastward till 10 P.M.; the mean deviation for the day varying through 9′ 8″. These are the mean movements, but they are modified seasonally. In summer the extreme range is 13′ 27″; in winter the minimum daily range is 7′ 2″. In winter the westerly movement is continuous throughout afternoon and night; in summer the eastward movement is continuous from 7 P.M. to 7 A.M.

324. Intensity.—The intensity of the magnetic force varies, being at a maximum at the magnetic pole, and in Siberia, for the northern hemisphere; near the magnetic pole for the southern hemisphere. The points of least intensity are near the equator in the middle of the Pacific, and near St. Helena in the South Atlantic.

325. **Magnetic Storms.**—The needles under observation are disturbed from time to time, and as these disturbances extend simultaneously over the globe, the influence to which they are due is presumably a very widely acting one. The relation of the magnetic storms to solar disturbances, indicated by changes in the form and position of the solar spots, has long been matter of observation; but their coincidence with auroral displays is better known.

326. **Aurora Borealis.**—At either pole a dark arch rises, whose plane is at right angles to that of the magnetic meridian. Above the dark arch the auroral light is developed as a band of light from which long peaks are projected to the zenith; or else a succession of concentric bands of light, separated by dark arches, gives the appearance of vertical curtains, seen in perspective, even the changing folds of the drapery being to appearance recognisable. The horizon of the auroras, or the line along which they are most frequently seen, extends from New York through St Petersburg, cities whose parallels of latitude are 15° apart, though they are approximately in the same magnetic parallel.

327. **Cause of Auroral Light.**—Spectroscopic investigations, conducted during the Scandinavian Polar Expedition, seem to indicate the presence in the atmosphere of iron and carbon in a fine state of division, and of snow as contributing to the character of the auroral light.

328. **Atmospheric Electricity.**—Pure air offers little or no resistance to the passage of electricity through it: in rarefied air the resistance is so diminished that it may be looked on as a conductor rather than as an insulator. Hence the intensity of electricity increases with height. The electricity of the atmosphere is positive, 10,000 observations, extending over three years, showing 3·17 per cent. of negative indications. In fair weather, Thomson found negative indications to precede a change from N.E. to a westerly wind, and explains it by the accumulation in the air, over any

locality towards which winds blow from different points, of the earth's electricity, conducted off by trees, etc. The condition of air and earth are then temporarily reversed, and the same result might be expected to follow a whirlwind.

329. Diurnal and Annual Changes.—The intensity of the atmospheric electricity varies periodically, increasing from June to January and decreasing again to June. The daily changes are more marked in winter than in summer. The following summary of his observations by Quetelet represents also the conclusions drawn from the extended observations at Kew:—

1. The electricity of the air, estimated always at the same height, undergoes a diurnal variation, which generally presents two maxima and two minima.
2. The maxima and minima vary according to the seasons of the year.
3. The first maximum occurs, in summer, before 8 A.M., in winter towards 10 A.M.; the second maximum occurs, in summer, after 9 P.M., in winter towards 6 P.M. The interval of time which separates the two minima is therefore more than thirteen hours at the epoch of the summer solstice, and eight hours only at the winter solstice.
4. The minimum of the day is towards 3 A.M. in summer, 1 A.M. in winter.
5. The mean electric state of the day is best represented about 11 A.M.

330. Relation of Electricity to Heat: Conductors.—Electricity is commonly spoken of as a polar force, as if it differed therein from other forces. But the conversion of heat into electricity, or, to speak more correctly, the change of that motion which appears as heat into that motion which appears as electricity, though unknown to us save by its results, is manifestly a change either in the transmissive power of the particles in a particular line, or an alteration in the line of transmission. The similar relation between electricity and magnetism, makes an illustration available from diamagnetism. Some bodies, held between the poles of a horse-shoe magnet, swing axially, others swing with their poles pointing towards those of the magnet. Among the diamagnetic substances, or those which placed themselves in the line connecting the poles of the magnet, is bismuth. Tyndall prepared a rod of bismuth powder, made firm by gum water, and found *it* possessed the property of the metal; but when the rod was laterally compressed it became magnetic, the molecular aggregation apparently controlling the direction. Between heat and electricity there is a remarkable coincidence in properties, by which both are conducted equally by the same bodies: a good conductor of the one is a good conductor of the other.

331. Conditions Affecting the Amount of Electricity in the Air.—The passage of a current is retarded by heat, accelerated by cold; hence the seasonal differences already stated, as well as those consequent on rarefaction. The amount of electricity may be said to vary with the amount of moisture in the air; but the movement of moist air develops no electricity by friction, unless the vapour has already assumed the vesicular form; in other words, has undergone some condensation. Probably the largest amount of electricity is due to chemical action: evaporation of perfectly pure water in still air develops none; but when compound solutions are evaporated, when, therefore, chemical combinations are formed or altered, electricity is generated. Hence combustion, as a particular case of chemical combination, is a source of electricity. When the evaporating compound is acid, and when combustion takes place, positive electricity is given off; when the solution is alkaline, negative electricity is given. And it is worthy of comparison with the effects of perfumes on radiation, that the relation is reversed by the presence of vapour of turpentine in the discharge pipe through which steam issues.

As pure air is as little retentive of electricity as of heat, the accumulation of electricity in it can only be in proportion to that of substances capable of retaining it, chiefly water. But mere moisture is not sufficient; the same quantity of water at different degrees of temperature occupies different cubic space in the air, and the electric intensity is in proportion to the density; hence the contrast in winter and summer, in the heat of day and the cold of dewfall.

332. Thunderstorms.—The formation of every cloud is therefore the accumulation of electricity; but if the formation is slow, equilibrium is maintained by the escape of a portion. But if *large* masses of vapour are suddenly accumulated, and if these are in opposite electric states, a spark passes between them, and this is continued till equilibrium is established. The reaccumulation may be very rapid, as in summer evenings, when the flashes continue for more than an hour from, at least apparently, the same cloud. Forked lightning is due to the breaking up of the flash by unequal conductivity of different atmospheric layers; this very frequently occurs when the spark passes between cloud and earth, though it also occurs when the spark passes from cloud to cloud. Sheet-lightning and silent lightning are probably the reflection on the clouds of thunderstorms at variable distances, beyond or just within the limits at which the thunder or its echo may be heard. Thunderbolts or fulgurites, the track of the flash through the soil, have been artificially produced with a large friction machine discharging into salt and sand, the vitreous tube thus formed exactly resembling those found in the desert. Whirlwinds and waterspouts have already been mentioned, but they must be referred to here as the gentler restoration of electrical equilibrium between the earth and the atmosphere, than that which takes place during a thunderstorm. The report heard after the flash is due to the sudden displacement of the air by expansion, and the consequent inrush to fill the space; its propagation is impeded by the resistance of the air, so that it does not travel so far as might be expected from its initial intensity. The number of seconds between the flash and the first sound of the thunder multiplied by 1090, the average velocity of sound through air, gives approximately the distance of the thunderstorm, in feet, from the observer.

CHAPTER VII.

CLIMATE AND WEATHER.

Climate and Weather — Relation of Temperature to Latitude — Equivalent Periods in both Hemispheres—Isothermal, Isotheral, Isocheimal Lines—Continental and Insular Climates—Influence of Currents; East and West Shores—Climate of British Isles—Climate of Lake Regions—Influence of Marsh Land—Form of Ground—Decrease of Temperature in Altitude—Influence of Barometric Pressure—Surface Temperature of Land and Sea—Influence of Vegetation—Changes of Climate—Cycles of Climate—Influence of Eccentricity of Earth's Orbit—Influence of Obliquity of Ecliptic — Coincidence of Extreme Eccentricity and Obliquity—Geological Evidence of Climatic Cycles—Influence of Geographical Changes—Weather—Deviations from Normal Temperature—Lunar Influence—Weather Prognostics.

333. Climate and Weather.—Climate was at first intended to express the annual temperature of a place, when temperature and latitude were believed to correspond. Additions have been gradually made to this limited meaning, and now it has even been used* to include food as one of the external conditions to which animals are subjected. This is, however, too extended a sense to give to a term for which at present no exact definition can be framed. Climate may be regarded as the general tendency of a district towards mild or severe, average or extreme, temperature, moisture, atmospheric pressure. Weather is the variation from time to time in respect of all or any of these conditions. A man's constitution is a popular phrase for his tendencies towards any particular kind of disease, and his capacity to endure changes: health means his daily departures from, or return to, this condition of equilibrium; for it is only in sanitary science that the health of a district means disease.

334. Relation of Temperature to Latitude.—The alternate exposure of the northern and southern hemisphere to the sun (Art. 2) destroys the parallelism to the equator of the zones of equal solar heat. As a consequence of the obliquity of its axis, the earth at B, which represents the northern summer solstice, has the sun above the horizon of any place in the northern hemisphere for more than twelve hours; and within the Arctic circle, that is, within 23° 27′ 30″, the sun never sets. As the temperature of a region is in proportion (omitting minor modifications) to its exposure to the sun's rays, the northern hemisphere receives, in this phase, as much more than the average as it receives less than the average in the opposite phase D, which shows the southern summer solstice. In the intervening positions A and C, the day and night are equal all over the earth; and at these times, spring and autumn respectively, the vernal and autumnal equinoxes, the solar radiation on both hemispheres is equal. Climate, therefore, presents for every locality a seasonal maximum and minimum. If the hemispheres were identical as regards the distribution of land and water, solar and terrestrial radiation would balance each other; but the northern, the land hemisphere, is more rapidly heated and cooled than the southern or water hemisphere. The summer and winter temperatures of the former are, therefore, extreme; of the latter, nearer the mean. The following, which shows also that the whole earth receives more heat in one half of the year than in the other, is Dove's approximate estimate:—

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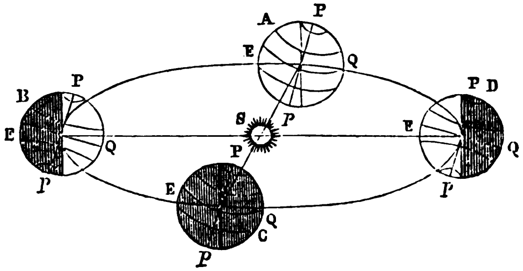
* Juke's *Manual of Geology*. Third Edition, p. 486.



	N. Hemisphere.	S. Hemisphere.	Whole Earth
Temperature for July,	21·6° C. (summer)	12°C. (winter)	16·7°C.
,, Jan.,	9·3°C. (winter)	15°2C. (summer)	12·3°C.

335. Equivalent Periods in Both Hemispheres.—The hottest month in the N. temperate region is July; in the subtropical regions, May and July; near the equator, April and August; at the equator, March and September. While, therefore, the greatest warmth of the temperate regions, north and south, is separated by six months from the greatest cold, there are, nearer the equator, two warm seasons. As these two hot months correspond to the passage of the sun across the equator, it follows that the interval which separates them decreases towards the poles, till at last the summer of June indicates the time when the sun approaches to verticality in the northern temperate zone. From this diagram the student will recognise the seasonal correspondences, the italicised names in the inner circle giving the cold seasons at each quadrant.

SUMMER SOLSTICE.
June.
December.
May. July.
April. August.
(Vernal (Autumnal
March. . . . . . . *June.* . . . . Equator. . . . *December*. . . . . September.
Equinox.) Equinox.)
February. October.
January. November.
June.
December.
WINTER SOLSTICE.

336. Isothermal, Isotheral, Isocheimal Lines.—Maps have been constructed on which the mean annual temperature of the earth is shown by a series of lines passing through the spots which have the same temperatures. But these isothermal lines only give a very general idea of climate. Thus, the mean of St. Louis is 12·2° C., of Algiers, 13·2°; but St. Louis has a summer temperature of 23·8°, a winter of 0·5°; whereas summer and winter in Algiers show 23·3° and 12·2°; it is this range of 23° in the one case, of 11° in the other, which characterises these two places. But St. Louis is 7° farther north than Algiers; New Orleans is 2° farther south; the temperatures at the latter place are: mean, 20·5° C.; summer, 27·7°; winter, 13·3°. The mean does not tell of the range through 14°, nor does the difference of latitude account for the higher mean.

Fully to realise all the conditions on which the climate of a region depends, would require the comparison of daily thermometric readings at many points. But the broad facts of the distribution of temperature may be gathered from isotheral and isocheimal maps on which the lines of equal temperature for summer and winter, respectively, are recorded, or are still more obvious from the quarterly charts.*

337. Continental and Insular Climates.—The influence of sea is well seen by the comparison of localities nearly on the same latitude. Thus :—

	Minimum.	Maximum.	Diff.	Mean.
Rio Janeiro, ...	20°C.	26·1°C.	6·1°C.	23°C.
St. Helena, ...	14·4°	17·7°	3·3	16°
Mauritius, ...	23·8°	27·7°	3·9	25°
Honolulu, ...	22·7°	26·1°	4·1	24·4°
Mexico, ...	12·2°	18·3°	6·1	15°
Batavia, ...	25·5°	25·5°	0	25·5°
Lima, ...	21°	25·5°	4·5	23·5°
St. Petersburg, ...	-7·2°	16·1°	23·3	4·6°
Reykjavik, ...	-1·6°	11·6°	13	5°
St. Louis, ...	0·5°	23·8°	18	12°
Kizeljelgah, E. Turkestan,	-17°	+3·8°	20·8	-7°
Nain, ...	8·8°	-15°	23·8	-3·6°
Fort York, Hudson's Bay,	15·5°	-20·5°	36	-3°
Sitka, ...	12·2°	0	12·2	6·1°
Edinburgh, ...	14·4°	3·3°	11·1	8·8°

These examples will serve to illustrate the extreme range of places, even on the shores of continents as compared with islands, on the same latitudes. The insular as compared with the continental climate is characterised by moderation, in consequence of the different specific heat of land and water (Art. 75). The isothermal lines show the greatest variations of curvature over land surfaces, least over ocean areas.

338. Influence of Currents: East and West Shores.—But the Gulf Stream gives a remarkable northward convexity of the curves, so that the summer temperatures at sea are considerably to the north of their proper latitudinal position, the winter isotherm of 5°C. reaching to 58° N. lat. in the Atlantic, to 50° N. lat. in the Pacific; on the other hand, it descends below 40° N. lat. on the American coast. The Arctic current thus indicates its course on the surface. Similarly, the summer line of 25°C. in the southern hemisphere is wavy, bending northwards with the prolongations of the Antarctic drift. The effect on the land climate is not by radiation, but by the passage of heated air from sea to land. Hence the western shores of the N. Atlantic are colder than the eastern. The mean annual temperatures of the following places show this:—

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* *Student's Atlas of Physical Geography*, Maps X. and XI.

Halifax, - -	44° 39′ N.,	6·2°C.	Faroe Islands,	62° 2′ N.,	7·1°C.
Boston, - -	42° 21′ N.,	9·6°C.	Dublin, -	53° 21′ N.,	9·6°C.
Falkland Islands,	52° S.,	8·2°C.	Port Famine,	53° 21′ S.,	5·3°C.

The third line shows the temperature of corresponding southern latitudes. In the S. Atlantic the west shores are the warmer, Rio Janeiro having a mean annual of 23°C., Cape Town of 17·7°.

But the warm air is accompanied to the land by moisture, and this, checking radiation (Art. 265), helps to maintain the temperature.

339. Climate of British Isles.—The summer and winter temperatures of the British Isles are instructive. Throughout the year the source of its higher temperature, the Gulf Stream, is indicated by the direction of the isothermal lines, which in winter are on the whole parallel to the trend of the coasts, in summer run from south of west to north of east. In winter, temperatures above 4°C. are found to south and west of a line from the Straits of Dover through the Isle of Wight, by Bristol, to the Irish Sea. The centre of Ireland averages 3·8°C., but the line of 4° embraces a narrow margin of the island on the east side, and a very broad tract of the south and west. The west coast of Scotland has an average of 3·8°C., the rest of Great Britain is 2·7°. In summer the relations are reversed; the highest temperatures are still to the south-west, but they now occupy the interior of Britain, and the temperature of places to the east is higher than that of places to the west on the same parallel of latitude. Hence, while the difference of summer and winter temperatures at Galway is 9°, in the valley of the Thames it is 15°. On a minor scale, therefore, the east part of the area approaches the continental character of climate. The difference between east and west would be greater, but that a portion of the cold water steals down as far as the west of Ireland.

340. Climate of Lake Regions.—In N. America, the freezing of the lakes seems to exercise the same influence as if they were solid land. The isotherm of 0°C. (January), curves to the south of the lake area, as far as it does over the arid continent of Asia, whereas in summer it retreats within the Arctic circle. The specific heat of water tells therefore in summer; but in winter, ice gives the same results as an equal mass of land. A similar deflection of the 0° line is due to the Baltic Sea.

341. Influence of Marsh Land.—The depth of water in the lakes gives them a beneficial effect in summer, whereas the evaporation of the thin layer of water over the swampy grounds of Arctic America and Asia has the opposite effect, of keeping down the summer temperature, as did the ill-drained lands of Britain in former times.

342. Form of Ground.—A mountain range acts in two ways; it forces the air into greater altitudes, refrigeration being the consequence; and it condenses the moisture, thus drying the wind. If the rarefied air descends on the other side it reacquires a part, but only a part, of the heat it had on striking the hill range, having lost a portion by radiation. But it has also parted with moisture; it offers less impediment to radiation, and hence the diurnal range of temperature is greater. Thus the Scandinavian chain separates two areas, of which the western shows a difference of 18° between the summer and winter temperatures, while on the east side the difference is 23°.

343. Decrease of Temperature in Altitude.—It has been already stated (Art. 269) that temperature diminishes with height, and that the diminution is less rapid, and less regular, away from mountains than in air which is in contact with earth. Solar radiation is more powerful at great heights, the air being drier, but terrestrial radiation makes up for this, and the nocturnal loss of heat powerfully aids the influence of rarefaction on the air in depressing the mean temperature.

344. Influence of Barometric Pressure.—It appears that the position of high barometric pressure strongly affects the temperature of particular regions. Buchan tabulates the barometric pressure over Europe* for several seasons of unusual warmth and cold, showing that when the pressure in January 1867 gradually diminished from 30·262 inches in Iceland, to 29·604 inches in Jersey, the cold was 3·5° below the average in Orkney, and 1·6 in Jersey, the mean temperature of Scotland being as much as 6·1° below the average of the month. Again, in November 1867, the pressure in Jersey was 30·278 inches, in Iceland 29·957 inches, a slight difference, yet the average temperature was above that of the month by 5·5° at Paris, 3° at Orkney. Lastly, in December 1860, the barometric slope was from 30·7 inches in Siberia, to 29·7 over Britain; and the mean temperature of eastern Scotland was 15° C. below the average on Christmas day. The movement of the air was along the slopes indicated, and these examples abundantly strengthen Buchan's appeal for the regulation of weather telegrams, as a certain means of enabling the physician to take precautions against dangers to health, as great as the dangers to shipping, to avert which storm warnings are issued.

345. Surface Temperatures of Land and Sea.—The depth to which daily variations of temperature are felt extends, for the sea, to 100 fathoms in the Indian Ocean, 50 fathoms in the N. Atlantic, the limit of constant temperature being 1700 and 1000 fathoms respectively (Art. 75). The curve of the snow line has already been stated (Art. 207). The limit of constant temperature of the soil is speedily reached. The soil can heat only by conduction downwards, and the impediments are such that the diurnal changes are probably nowhere perceptible beyond four feet. The evaporation from different soils has already been mentioned (Art. 174). The heat of the surface also depends on the character of the soil, sand attaining the highest temperature, 70° in S. Africa; but the Arabian and N. African mean is 33° to 35°C. The more compact the material, the greater may its conductivity be in general expected to be; hence the lower temperature of solid rock than sand. Clays, on the other hand, are shielded by evaporation from the sun's direct rays.

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* *Handbook*, pp. 129 *et seqq.*

346. Influence of Vegetation.—Plants protect the soil from being highly heated, radiation preventing the accumulation of heat. On the other hand, the moisture which accompanies vegetation helps to maintain a more equable, and therefore a higher mean temperature.

The importance of forests has already been more than once alluded to (Art. 60), and it is only necessary here to point out that, as their evaporation increases the rainfall, and as the condensation of moisture liberates a certain quantity of heat which became latent on vaporization, the direct as well as the indirect influence of vegetation on temperature is considerable.

347. Changes of Climate.—The investigation of the changes on the earth's surface has prepared the student to understand the influences by which climate may be altered:

a. Elevation or depression of a coast line may alter the direction of currents.

b. The greater or less height of a mountain chain may stop or permit the passage of the winds from one basin into another; even the lowering of a pass is of importance, since migratory birds, though high in air, are found to follow the Alpine passes in their southward flight.

c. The deflection of a warm or cold current, as of the Gulf Stream or the Labrador current, would be productive of considerable change.

d. The removal or the increase of vegetation.

e. The draining of land.

All these are sources of slow change, and their occurrence is irregular, as the movements on which chiefly they depend are not subject to any law, so far as is yet known.

348. Cycles of Climate.—But the facts mentioned in the first chapter regarding the earth's varying distance from the sun, and the phenomena of precesssion and nutation, correspond to variations in the amount of heat received from the sun by different parts of the earth's surface. And as these are periodically recurrent, though the intervals may be affected by the attraction of other planetary bodies, astronomical cycles *correspond* by their indirect influence to climatal cycles. Changes of physical geography, modifications of the distribution of land and water, may increase or diminish the temperature of particular regions, but they are subordinate and uncertain influences compared with the astronomical.

349. Influence of Eccentricity of Earth's Orbit.—When the eccentricity of the earth's orbit is at the maximum, the earth in aphelion would be 8,641,876 miles more distant from the sun than now. The two hemispheres would have very different temperatures if the winter solstice of one happened in aphelion. The northern hemisphere would be reduced by 25° C., while the southern hemisphere, the winter of which occurred in perihelion, would enjoy a more equable climate. In consequence of the great reduction of temperature in the north, the thermal equator would be much to the south of its present position, the north-east trades, representing the return of the westerly currents arrested far to the south of their present limit, would have greatly increased force, and, crossing the earth's equator, would drive the warmer tropical waters to the south, so that the equatorial drift would not enter the Caribbean Sea. Now, as the temperature of Scotland is 15·5° C. in excess of that proper to its latitude, the withdrawal of the Gulf Stream would lower the temperature by that amount; and as that current of warm water carries to the north 3234 times the heat which would be conveyed by a current of air of the same volume, the cessation of that influence, and its transfer, even in a modified form, to the Antarctic regions, would be of great importance. But the northern summer occurring in perihelion would be, at first sight, very warm. It must be remembered that the winter cold would cause precipitation to take the form of snow, and the summer heat would be largely spent in melting the winter's accumulation; but melting leads to evaporation, and the fogs thus resulting stop the heat rays from the sun, while the snow and ice reflect the heat rays, and, at the same time, cool the air by contact. A warm summer, therefore, ministers to the snow and ice of the pole. The transfer, under the influence of the strong N.E. trades, of warm water to the south pole, would tend to diminish the ice there, and ultim[illegible] remove it. The loss of heat by radiation into spac[illegible]rm air at the equator sustains by ascending into higher altitudes, must also be taken into account, since it diminishes the influence of a warm summer. The reversal of the winters, the occurrence of the northern winter in perihelion, would lead to a contrary condition of things; and the Gulf Stream would then have as much more heating power than it at present possesses in northern latitudes, as it had less in the case just stated. It follows from the relative power of warm water currents, as compared with warm air currents, that an equatorial ocean would have much greater power in moderating the severity of the polar climate.

350. Influence of Obliquity of Ecliptic.—The maximum obliquity of the ecliptic (Art. 1) would, according to Meech's calculations, increase the amount of heat received at the poles by $\frac{1}{18}$, that is, if the thermal days at the equator at present are 365·24, and at the pole 151·59, these numbers would be, at the maximum obliquity, 363·51, and 160·04 respectively, a diminution of 1·73 in the one case, an increase of 8·45 in the other; and this increase of $\frac{1}{18}$ would represent a rise in the mean annual temperature of the poles to the extent of from 7·5° to 8·5° C., if the polar region were free of ice and snow; but the increase of temperature would, in reality, be spent in melting part of that ice and snow, the air not rising above 0° C. The conjunction of extreme eccentricity and obliquity with winter in aphelion would be to moderate the severity of the climate of that hemisphere whose winter occurred in aphelion, and to diminish the ice at the opposite pole. But the conjunction of maximum eccentricity and minimum obliquity would tend to increase the cold of the aphelial winter, and to diminish the warmth of that in perihelion.

351. Coincidence of Extreme Eccentricity and Obliquity.—The coincidence at remote periods, say 11,700 years ago, is not determinable with certainty, nor is the rate of precession uniform so far as is known. Mr. Croll gives 11,700, 33,300, and 61,300 years as periods when the winter solstice of the northern hemisphere was in aphelion, the intervals being 21,600 and 28,000 years respectively, and to this extent, therefore, the statement in Art. 6 must be modified. The *further back* calculations are carried, the less certain become the periods at which phenomena are believed to have occurred, the greater the chance of perturbations having interfered with the regularity of the movements. All that it is proposed in these paragraphs to indicate is that, in obedience to laws, the details of whose operations are not known with certainty, the position of the earth relatively to the sun has changed, and the temperature of the north and south hemispheres has varied in correspondence with this change.

352. Geological Evidence of Climatal Cycles.—Within the Arctic circle the remains of plants and animals proper to regions now greatly warmer have been found, and, beyond the limits of existing species, carboniferous fossils prove resemblance, even identity, of forms in polar and temperate regions. The foregoing paragraphs suggest that these facts are explicable by reference to astronomical movements, whose date we cannot, however, even approximately determine. The presence of the elk, rhinoceros, and hippopotamus, in Europe, is among the most recent palæontological evidence of change of climatal conditions; while the boulder clay and striated rock surfaces bear testimony to a recent period of great cold in regions where formerly permian, old red, and cambrian glaciers probably existed. The student will find the full discussion of this most interesting problem in Mr. Croll's papers in the *Reader* and *Philosophical Magazine* since 1864, and in Sir Charles Lyell's *Principles*, vol. i.

353. Influence of Geographical Changes.—The position of the great masses of land at the poles, or at the equator, is an important element in the change of climate. Equatorial land would part more rapidly with heat into the air, and radiation keeps the upper strata of the atmosphere cool, in conjunction with rarefaction. It would also diminish the area of warm water at the equator, and stop its movement toward the poles. An equatorial ocean and polar land is a hypothetical case, the conditions of which it is not easy to determine; but, supposing that the preponderance of land lay at the poles, and that in equatorial and temperate regions there were still land masses (and there is no reasón for believing that land has ever ceased to exist in those regions), the arrangements would be presented by which atmospheric and oceanic circulation would take place as at present, though the details might not be identical.

354. Weather.—The student will have seen that much of what has been said regarding temperature might be considered as affecting weather, not climate, and will therefore be prepared to recognise climate as the mean of the weather, thus making both terms the symbols of different quantities of the same thing.

355. Deviations from Normal Temperature.—There is seldom a regular gradation of temperature from the hottest to the coldest months, or the converse. The departures from a regular movement are either storms, or periods of heat and cold in excess of that proper to the season. Some of these deviations recur with great regularity, and are due to variations in barometric pressure, such as have been already mentioned, and which are probably determined by equatorial disturbances of greater or less area. The deviations observed in Scotland, and some of them are also European, are as follows:*—

Cold,	7-10 Feb.,	11-14 Apr.,	9-14 May,	29th Jn.-4th Jy.,	6-11 Aug.,	6-12 Nov.
Warm,				12-15 July,	12-15 Aug.,	3-9 Dec.

356. Lunar Influence.—Popular tradition assigns great power to the moon, and the lower temperature, after full moon, has been ascribed to lunar heat dispersing clouds and increasing terrestrial radiation. What the lunar heat may be which is arrested in the atmosphere we cannot tell, but Zenger† has shown, from a large number of observations, that changes in the moon's distance are really followed by differences of temperature. The preponderance of S. and W. winds in the first, and of N. and E. winds in the last half of the moon's revolution, is an isolated observation as yet; but it is worthy of inquiry whether there are not in truth atmospheric tides as there are of the ocean, movements not identical in kind nor coincident in time with those of the sea, but to which some peculiarities in the distribution of barometric pressure may be traced.

357. Weather Prognostics.—These belong to the province of practical meteorology, at present an empirical branch of science, and likely to remain so till long time or increased points of observation shall yield the data on which more certain principles shall be established. At present the careful application of physical laws to data, comparatively scanty, has led to conclusions, the general accuracy of which is popularly discredited by the dishonest use which ignorance and prejudice make of the failures.

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* *Buchan.*

† *Philosophical Magazine*, 1868.

CHAPTER VIII.

Hypogene, or Subterranean Changes—Intensity of Forces—Volcanoes—Structure of the Cone—Ashes in Sedimentary Deposits—Transport of Ashes: their Size and Composition—Texture and Composition of Lava—Quantity of Lava poured out—Alteration of Cone and Crater: Course of Lava below Ground—Dormant and Extinct Volcanoes—Distribution of Volcanoes—Latitudinal Volcanic Chains—Earthquakes—Earthwave Twofold—Form of Earthwave—Modification of the Wave Shells—Earthquake Wave at Sea—Tests of Direction of Movement—Change of Surface—Phenomena accompanying Earthquakes—Area of Disturbance—Distribution of Earthquakes—Causes of Volcanoes and Earthquakes—Hypothesis of connection between Sea and Volcanic Centres—Vapour and Thermal Springs—Intermission of Geysers—Periodicity of Earthquakes and Volcanoes—Secular Movements of the Earth's Crust.

358. Hypogene, or Subterranean Changes.—Volcanic eruptions, earthquakes, and upward and downward movements of the earth's crust, may occur apart or in conjunction, or may succeed each other so as to suggest that their development is alternative. Their association thus renders them a natural group for systematic description, if it does not necessarily indicate their common origin. But the operations to which the metamorphism of rock masses is due, whether they have been chemically or mechanically altered, or have undergone both changes simultaneously or in succession, are for the most part without equivalent in degree at the surface of the earth, though they may have representatives in kind. In the present imperfection of our knowledge regarding the chemistry of metamorphism, it is safest to keep that subject apart from those previously mentioned, and to disregard to some extent the probability of the common origin of all these phenomena.

359. Intensity of Forces.—From the necessarily slow changes in a rock undergoing alteration—through the oscillations of level which are so gradual that even a minute change is only detected by comparing the records of generations—to the earthquake which ruins a region, and may have its horrors intensified by simultaneous volcanic eruption, there is a scale of intensity which, if estimated by work done in equal times, is in the order of enumeration; but, if tested by the total of work done, the volcano is dwarfed by the side of the slow elevation.

The volcanic outburst, it must be remembered, is only the last in a long series of events: it represents the slight excess of force in some direction which overthrows the balance and sets in motion operations which tend to restore equilibrium. Violent as the eruption may be, it is only a symptom; it cannot be regarded as more than a very subordinate event, and in speculating on the progressive diminution of volcanic energy, it is not the outburst but the force of which it is the expression, that must engage our attention. Now, the occurrence from time to time of violent events is a part of the doctrine of uniformity, which means identity in kind, but not necessarily in degree, of the processes which have gone on at all times of the earth's history. The degree may have varied, so that the intensity is greater now, or was greater in the past than now. The amount of energy in the earth is undergoing diminution, but at what rate we cannot tell: if we assume that volcanic activity depends on a store of materials, or of force which has not been renewed, the diminution in amount of volcanic activity is a necessary consequence of the tendency to equilibrium manifested by all chemical change. But geology gives no reason for believing that there has been less activity in recent times, and furnishes evidence that defective observation has exaggerated the intensity of the past, by massing together events which were really far apart. On the other hand the conflict of opinion among competent chemists and physicists, as to the conditions of volcanic activity, proves that speculations are far from resting on a sufficiently wide induction of facts, and that even the chemical elements of the problem are undetermined.

360. Volcanoes.—In such long mountain chains as those of America and Central Asia, numerous volcanic peaks occur which were not the cause of the mountain elevation, and may have been developed at any period before or since the elevation. The most obvious phenomena connected with volcanic outbursts are the events which take place at and near the seat of eruption. The majority of the orifices by which material escapes from the interior of the earth's crust open on the summit of elevations of greater or less height. Usually the crater of the volcano, as this aperture is denominated, opens on the top of a conical hill, more or less abruptly truncated, and for the most part having one side higher than the other, the smooth outlines of the cone contrasting with those generally presented by ordinary denuded hills. The crater gives exit to lava, ashes, steam, sulphurous vapours, nitrogen, hydrogen, and hydrochloric acid. Several of these are present in all eruptions, but in very various quantities. The lava may be the principal material; in others no lava flows out, only ashes are driven forth, or hot water, sulphurous vapours, or other gaseous emanations may escape alone. Lava pours out of the orifices of the crater, or, as very frequently happens, through apertures upon the side of the cone; it flows out in a stream or *coulée*, which may not descend below the cone, or may travel down to the plain, and even—if the quantity of lava is large—pass for miles over the adjacent country. The slope, at first high, as much as 30°, gradually becomes less as the stream approaches the low grounds, until it finally terminates, usually with a more or less vertical face. This description applies to the typical volcano, consisting of a cone, through which passes a single supply pipe. But such a simple case is of comparatively rare occurrence, the volcano, for the most part, presenting a complicated structure, due to the presence of several orifices more or less distinct from each other.

361. Structure of the Cone.—The cone, as has been said, terminates the truncated extremity, and its orifice leads into a funnel-shaped cavity, the materials on the sides of which slope downwards towards the orifice of the supply pipe. The greater height of one side is due to the manner in which a cone is formed; for the volcano is not a mountain of elevation, it is in reality a mass which grows at the summit. Volcanic ashes, that is to say, the molten matter which is blown into a coarser or finer powder by the force of the explosions, are thrown upwards, and descending for the most part round the orifices, gradually pile up a hill which has the same typical form as the heap of sand in the hour-glass. If the prevalent winds have any strength, the high side of the volcano will be to the leeward, and by repeated eruptions the height of the mass may go on steadily increasing. Its incoherent materials are liable to be suddenly removed, as has happened in Java, where the cone has suffered a diminution of 4000 feet after the close of a series of eruptions. If a long period of quiescence follows, the cone becomes affected by atmospheric waste; its height is slowly reduced, and ravines are furrowed out of its sides, so that, as Junghuhn said of the Javan cones, they look like umbrellas, the ridges representing ribs.

362. Ashes in Sedimentary Deposits.—The ashes, however, do not always fall in the immediate vicinity of the crater; they may be transported to a considerable distance. If they fall into the sea, they become incorporated with the sedimentary deposits there going on, which thus present transitions from the purely volcanic to the purely sedimentary formations (diagram, p. 25). Again, steam is the almost constant accompaniment of eruptions, and, becoming condensed immediately after its ejection, is precipitated upon the surface of the volcano, carrying with it the finer ashes, and, flowing down towards the lower grounds in a stream of mud, is perhaps as destructive as a stream of molten lava. These floods, known as *moya* in South America, form deposits which, if preserved by subsequent lava flows, offer a close resemblance to subaqueous accumulations.

363. Transport of Ashes.—But the force of the eruption may carry the ashes into the air for a considerable distance, so that they may actually pass into the upper stratum, and be carried by the steady westerly winds. Thus, in 1815, the ashes of Sumbawa were carried to Amboyna, a distance of 800 miles to the north-east; the ashes of Coseguina were carried to Kingston in Jamaica, a distance of 700 miles, in four days; while the ashes of Hecla reached the Shetland Islands, transported, however, in this case, by a lower current, to the S.E. The quantity of this kind of material is various. What it may be, however, is suggested by the fact that eight leagues to the south of Coseguina the ashes formed a layer of three feet in thickness; and ashes formed the chief part of the material which buried Pompeii and Herculaneum.

364. Size and Composition of Ashes.—The size of the ejected material varies very much: blocks as large as an ox have been thrown out, and, falling upon sedimentary strata in course of formation, have sunk into them. The soft layers are carried downwards by the weight; new layers, as they are laid down, arch over the block, and thus a record is preserved of the periods at which eruptions may have occurred. The quality of the ashes varies with that of the lava in the same eruption; being, therefore, siliceous or basic, as will be immediately explained

365. Texture of Lava.—The lava poured out varies in character, being in some cases more tenacious than in others: thus, Von Buch describes the lava of 1805 as shooting down the cone of Vesuvius, the velocity being probably several hundred feet in a few seconds; but, for the most part, it is somewhat more viscid. Whether it overflows the lip of the crater, or passes out by lateral orifices on the cone, it parts with its heat rapidly from the surface, and thus becomes coated with a dense layer, which gradually retards its speed. The vertical section of a lava flow shows that the central portion of the mass is more compact, while the upper and lower surfaces form a layer of scoriæ of greater or less thickness, the included gases expanding as they approach the surface, and escaping with more or less violence at the upper surface, so as to give the coulée that ragged aspect which is preserved in some of the Auvergne outflows as freshly as if they had been of yesterday. Rock being a bad conductor, the formation of this hardened outer layer diminishes the speed of radiation, and thus the heat of the central mass may be retained for a considerable time; thus the lava of Jorullo retained sufficient heat after eight years to light a cigar a few inches below the surface. It is this incrusting of the mass with a solid covering which gives to the termination of the coulée its usually abrupt form.

366. Composition of Lavas.—Lavas are trachytic, or doleritic; contain, that is to say, a larger amount of silica on the one hand, and of the heavier basic ingredients on the other. The mean composition of the two types is given below:—

	Trachytes.	Dolerites.
Silica, ...	66·5	51·0
Alumina, ...	17·0	14·0
Potash, ...	5·0	0·2
Soda, ...	4·0	3·4
Lime, ...	1·4	10·0
Magnesia, ...	1·1	5·5
Oxides of Iron and Manganese,	3·0	14·7
Loss by ignition, ...	1·0	1·1

But though these varieties frequently occur separately, they are also met with in combination as a product of the same volcano, being either discharged by distinct orifices, or at the same orifices at different periods, giving rise to alternate layers of the two species. As their specific gravity is different, that of trachyte being, on the average, 2·6, while the dolerites are nearly 3, it has been suggested that they represent different layers of molten material in the interior. But the fact of their indiscriminate occurrence makes it more probable that the difference is due rather to the mode of segregation from a common mass than to any original differences in the source of supply. Similarly, in one and the same coulée varieties in the proportions of the ingredients may be found, due to the greater or less distinctness of the crystallization, or, in other words, to the greater or less pressure to which the mass has been subjected; and the differences must be borne in mind, as they help to explain the unequal modification which lava flows have undergone. The scoriæ resemble the slag of a glass furnace, and they may present the appearance known as ropy, if, by the onward movement of the lava, they become twisted and carried forward in curved lines, which recall the curves across the surface of a river or of a glacier. By the onward movement the gas bubbles, striving to reach the surface, may be protracted so as to present, not spherical, but lenticular, cavities, or even elongated lines, a character of use in the more ancient lavas or trap rocks, as enabling us to recognise the direction in which the stream has moved.

367. Quantity of Lava at one Eruption.—The total quantity of lava emitted at one eruption is very various;

the coulée may never pass beyond the cone, or it may, like that of Skaptar Jokul, Iceland, in 1783, extend over forty-five miles, with a varying breadth of seven to fifteen miles, and a depth of one to six hundred feet, a mass which, as Lyell calculates, would stretch from Hampstead to Gloucester. The quantities poured out in the older formation often cover an enormous area, and to a great thickness. But it is impossible to recognise the portions belonging to indivdual outflows, and the position of the crater is equally beyond our knowledge.

368. Alteration of Cone and Crater.—It has been mentioned that a crater is an incoherent mass consisting wholly of ashes, or of lava and ashes interstratified. Such a structure is not likely to be permanent, and it is only very rarely that we find any trace of the actual crater of volcanoes which have, since their formation, been exposed to marine denudation. Etna offers a grand example of this: the Val del Bove is excavated by atmospheric waste to a depth of 3000 feet, entirely out of the softer materials of many outpourings. The summit of Arthur Seat, at Edinburgh, is a fragment of a tertiary cone, part of the ashes being still preserved in place as they lay round the orifice, which is now filled by a plug of basalt.

369. Course of Lava below Ground.—The ancient trap rocks give us information as to what may be called the anatomy of the volcano. The diagram (Art. 27) sums up that anatomy, and shows that between the contemporaneous and the so-called intrusive masses there is no distinction save that of position, and of such textural characters as result from greater or less pressure, or speed of cooling. Every volcano breaks through sedimentary strata; and whether the direction of outburst is determined by the effort of the lava to reach the surface, or the lava takes advantage of fissures already created (and both things may have concurred), it is certain that in its upward progress, more especially if movement be retarded at the surface by any cause, the force from behind will compel the molten matter to escape in any direction, wherever a line of weakness exists. It would, therefore, tend first to pass between the planes of stratification. The direction of the lava would be altered, further, by joints or fissures across the strata, and, if it actually reached the surface, its place of escape would be regarded as another lateral orifice. It is this mechanical tendency to take advantage of weak points which originates the many dykes that traverse the cones of most volcanoes. Denudation makes the position of dykes obvious by wearing away the sedimentary strata; but the trap itself is sometimes wasted so as to leave a parallel-sided gap: the projection in the former case, the gap in the latter, correspond to the Scottish and Cumbrian sense of the word dyke, respectively.

370. Dormant and Extinct Volcanoes.—We do not know if any volcano, now quiescent, is extinct in the sense of final cessation of possible activity. Probably there is no such extinction any more than there is reason to believe that a volcano cannot break out at a spot where such an event never happened before. A volcano may be quiescent for centuries, and its dormant state may end in a very violent and long-continued period of activity. We cannot even regard as proof of extinction an interval of, it may be, many thousand years, since, for aught we know, the processes which terminate in an outburst may be going on beneath, but do not make themselves manifest, either because the operations are slow, or because their tension is relieved in other directions. Thus the interval between the carboniferous and the tertiary eruptions in Scotland was probably greater than that between the tertiary and the present time.

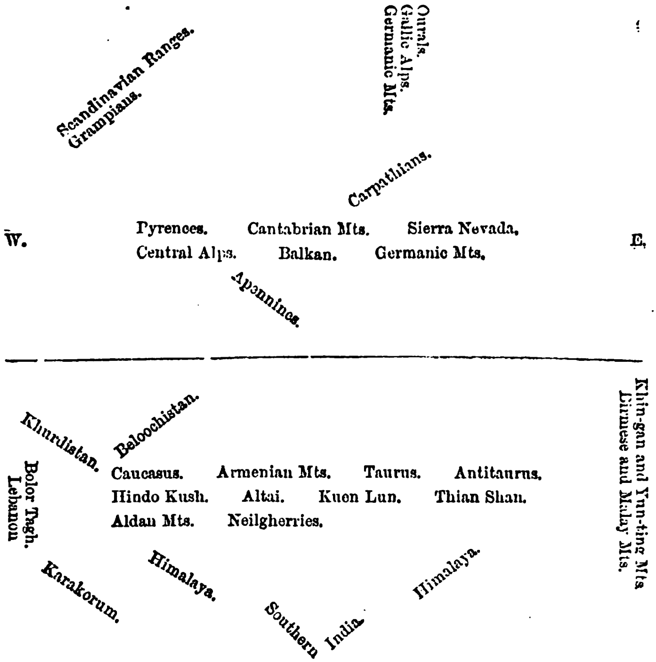
371. Distribution of Volcanoes.—The distribution of volcanoes over the surface of the earth at the present time presents a certain kind of system, and lines may be traced as mountain chains have been traced, though in the one and in the other case we cannot regard these lines as evidences of simultaneous action at all points. We ought properly to look upon them as a series of successive actions, which, occurring at different periods, have maintained the same general direction. The American continent furnishes the most continuous line. The continuity, taken in conjunction with the alternating activity of different points, suggests that they are situated over a single longitudinal fissure. Commencing at the south we have those of Fuego, the highest of which is 7000 feet, and the Patagonian volcanoes, situated about

54° south latitude. In the Andes the chain extends from 43° to 30° lat. S., and numbers more than thirty peaks, Aconcagua being the highest; those of Bolivia, seven or eight in number, from 21° to 15°; the Quito district, from 2° lat. S. to 3° lat. N., includes about twenty peaks, nearly all above 14,000 feet of elevation. About 9° lat. N. the volcanoes of Central America, Mexico, and Western America commence; nearly sixty are known, and several are recorded whose history is, however, imperfectly known. The series terminates in Mount St. Elias, whose height is about 18,000 feet. The great Mexican volcano, Jorullo, is 123 miles from the nearest ocean, but the rest present the usual relation of most active volcanoes, namely, close proximity to the coast line. The West Indian Islands are connected with this great north and south line by a line passing from Quito through Granada. The West Indian Islands form two parallel chains; in the western there are ten volcanoes, while the eastern consists chiefly of calcareous rock. The American line is connected with the Asiatic by a chain stretching through the Aleutian Islands, of which more than twenty are volcanic, to Kamtschatka, which contains about twenty volcanoes. Southwards, the Kurile Islands, twelve of which are volcanoes, and the Japanese group, with twenty-five, form a fringe on the west shores of Asia. In the Philippine Islands, with about twenty volcanoes, the chain is traversed by a very numerous series, passing from the Indian Ocean eastwards to New Guinea, through Sumatra and Java, each of which contains about fifty active or dormant volcanoes. The line curves away to the south-east of New Zealand, and nearly completes a ring round the Pacific. Though the general direction of the line thus traced is tolerably continuous, it is probable that detailed enquiry will prove the existence of several distinct axes belonging to different periods of activity; but it is interesting to note that the two opposite shores of the Pacific manifest exactly the same kind of distribution of the volcanic chain. Another line has been traced from the borders of China westwards into Asia Minor, and thence by the Mediterranean to the Cape Verde Islands; but the interruptions of this line prevent us from regarding it as a common axis. It is certain that Spain and the north-west of Africa form a single volcanic region, while the north-eastern corner of Africa, with Arabia, is singularly free from all record even of former activity. Isolated volcanoes occur which cannot be associated with any of the recognised lines; thus, in the North Atlantic, Jan Mayen and Iceland are separate centres, though they may possibly be connected. Passing southwards, the Azores, the Cape Verde Islands, the submarine eruptions at the equator, Ascension Island and Tristan d'Acunha, form for the most part perfectly isolated volcanoes, though two of them, the Azores and the Cape Verde group, have been held to belong to the Mediterranean axis. St Paul's Island and the Mauritius group are likewise isolated, and other volcanoes have been recorded still farther to the south, whose relations, however, are absolutely unknown. The diagram on p. 66 is intended to show the deviation of the axial lines among the islands of the Pacific. The remarkable way in which they contrast with the lines of existing continents is of great interest in connection with the hypothesis that the Pacific and part of the Indian Ocean were, since the appearance of man on the earth, the seat of a continent, that it had been so for long ages previously, and that Australia, New Zealand, Tasmania, are the last fragments of this changing land surface (Art. 38).

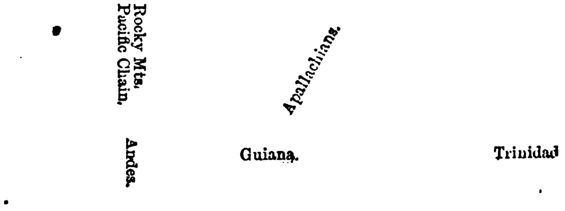
372. Latitudinal Volcanic Chains. — The volcanoes hitherto spoken of are either on the margins of continents, in chains of islands, or isolated in ocean. But the mountain lines across Asia are to some extent associated with volcanic phenomena, mud and vapour vents occurring at intervals across the continent. But these are most numerous in the western area, near the Ponto-Caspian area, and no active volcano exists in the interior, far away from a water area. The subjoined diagram shows the relations of the leading mountain chains to the lines of volcanic activity, enumerated in last paragraph.

373. Earthquakes.—An earthquake is a vibration of the earth's crust, a disturbance whose effects are immediately appreciable, which is therefore connected with violence. The movement of the surface of Vesuvius before an eruption is only detected by Palmieri's delicate instruments, but it fore-

MOUNTAIN AXES OF EUROPEO-ASIATIC CONTINENT.



MOUNTAIN AXES OF AMERICA.



tells and passes into that violent action amid which even thunder is unheard.

374. Earthquake Wave Two-fold.—A shock of some kind is communicated to a mass of the earth's crust; it gives rise to two distinct movements: 1. The shock displaces the particles relatively to each other, at the point of impact, and this displacement tends to travel in a straight line. 2. From the point of shock a wave of elastic compression travels forwards at right angles to the line of shock. The latter travels more rapidly than the former. In the Calabrian earthquake, Mr. Mallet found that the rates were 789 : 13 in feet per second. Reverting to the definition of a wave given in Art. 38, the student will see that the transmission of the *wave-form*, each particle returning to its place, must be more rapid than the propagation of motion in which each particle displaces that which precedes it. Standing on the shore on a calm day when steamers are passing at various distances, it will be seen that each steamer causes two sets of waves to break, the one later than the other, by an interval which is directly as the distance of the steamer. The first waves are those of elastic compression, which are converted into movements of translation against the shore; the second, more powerful, are the waves of displacement.

375. Form of Earth Wave.—An upward blow on the earth's crust tends to travel vertically upwards, and this, the seismic vertical, produces at the surface a vertical displacement upwards and downwards; but from the point of shock other waves reach the surface at angles which gradually increase with distance, the tendency to horizontality of the consequent movement likewise increasing. Thus, if C is at the surface of the ground, the line A B C is the seismic

4 3 2 1 C 1 2 3 4
B
A

vertical. If B is the point of impulse, lines B1, B2, B3, represent the increasing angles of emergence; the intensity of the shock is inverse to the angle, and the tendency to horizontality increases till the line of shock is at right angles to the vertical. If the disturbed medium were homogeneous, the points 1 1, 2 2, 3 3, which are the coseismic points, would be in the circumference of circles; and the angle of emergence would be equal all round the seismic vertical as a centre. The waves would thus form conical shells. The deeper the point of shock, as at A, the acuter the angle of emergence, A1, A2, etc., to start with, and the wider the area over which the concentric shells would extend. It is obvious that, though the sensations of an observer suggest that the ground undulates from the point C outwards, the undulation is in reality made up of a series of movements at many consecutive points of the surface, and each of these starts independently from A or B. If, therefore, the direction of movement at 1, 2, 3, could be ascertained, the depth of the point of shock might be calculated. This is the substance of Mr. Mallet's teaching, and the perusal of his reports to the British Association will repay the student who desires to follow the application of mechanical principles to natural phenomena.

376. Modifications of the Wave Shells.—But the medium is not homogenous: it consists of layers of different texture, density, and thickness; and as the earth wave, like other waves, is due to reflection and refraction, the figure which the coseismal points would describe on the surface must vary. In the foregoing diagram, the lines 1A1, 2A2, represent inverted cones, with a circular base on the surface of the ground, but by such inequalities of movement as have been suggested, the circle may become an ellipse, or some still more irregular figure. A fault line in sedimentary strata has its direction altered in passing through layers of different density, as the ray of light is deflected in passing from air to water; and the earth wave undergoes the same change of direction, so that the area at the surface, bounded by any set of coseismal points, may be smaller or larger than it should be were the angle of emergence, proper to the distance of these points from the vertical, at its normal value.

377. Earthquake Wave at Sea.—Though these movements at sea are not registrable like those on land, it is obvious that, after the earth wave is communicated to the water, its behaviour will be more regular in the homogeneous fluid, and the movements already produced will travel with less unequal speed. The wave of translation thrown on the land, always a powerful agent of destruction, depends for its power on one or two conditions. Thus the horizontal tendency increases from the seismic vertical to a certain point, whose distance depends on the depth below ground of the shock, diminishing thereafter. If it strikes on a shelving shore, it gathers strength as it advances, in the same way as the tidal wave under similar circumstances.

378. Tests of the Direction of Movement.—As the plane of the wave tends to coincide with that of the earth's surface, its effect on buildings varies. The less the angle of emergence, the greater is the intensity, and the more of the vertical height of a pillar or building which shares in the horizontal movement. Hence, near the vertical, a pillar of six feet high will be thrown forwards; at a greater distance the base will be shifted forwards, but the inertia of the upper part will make it fall behind, as a man falls when a carriage suddenly moves. A wall running in the direction of the wave is fissured at right angles to its plane, so that if the wall and the wave are, say, in a plane from E. to W., the fissure will be oblique from above downwards, from W. to E.

The twisting of spires seems due to the reflection of the wave, and to be the joint product of the first and second movements already mentioned.

Fissures of the ground take place in very irregular fashion, either at right angles to the line of shock, or radial, as if vorticose movements had occurred.

379. Changes of Surface.—These fissures may be temporary or permanent; in the latter case they sometimes become the seat of mud or other springs. The permanent elevation of coast lines, as Chili and north Australia, and the conversion of valleys into closed basins, as has probably occurred in the Andes, are interesting as connecting these sudden violent disturbances with the more gentle movements of elevation and subsidence. Equally interesting is the formation of lakes, as in the Sunken Country of the Missouri in 1812.

380. Phenomena Accompanying Earthquakes. — The phenomena accompanying earthquakes are, as Mr. Mallet sums them up—1, The great earthquake wave; 2, the wave which is formed by the vertical displacement of the ocean floor, and the consequent overflow, in all directions, of the water thus elevated; 3, the wave of sound through the earth, which may or may not precede that of the shock; 4, the wave of sound transmitted through the air or sea; 5, the great wave of translation which represents, in the sea, the displacement effected by the emergent movements of land.

381. Area of Disturbance.—The area over which earthquake movements are felt is often considerable; but an uncertainty prevails when very great distances are alleged to be included under one movement, more especially when sea intervenes between the different points affected; for we cannot be sure that there have not been intermediate points of disturbance which have escaped observation, while their results seem to carry forward the one recorded event.

382. Distribution of Earthquakes.—The earthquake areas on the surface of the globe correspond generally to the volcanic districts; and it is noteworthy that, for example in the case of the Mediterranean, disturbances extend upon either side of the long axis which passes through that region, the phenomena showing, at least northwards, where they have been best observed, gradual diminution of intensity. Beyond the Alps tremors are experienced even as far as the British Islands; and the considerable disturbance which coincided with the great earthquake of Lisbon in 1755, was looked upon as proof of the extent to which that shock reached. It is possible, however, that the tremor in Scotland was a simultaneous—one might call it a sympathetic—disturbance, due to alterations in the subterranean cavities consequent upon the great change to the south. The process, whatever it was, which overthrew Lisbon, probably disturbed the relations of the fluid cavities which, as has been already stated, are believed by Sir William Thomson to exist.

383. Causes of Volcanoes and Earthquakes.—The belief in the common origin of earthquakes and volcanoes rests upon the very frequent coincidence of earthquake movements with volcanic outbursts; and probably no great developments of the latter ever take place without very important developments of the former. In the Mediterranean area a remarkable alternation has been observed between the volcanic eruptions of the Archipelago and the earthquakes of Syria; and the same relation is believed to exist between Ischia and Vesuvius. These alternations are similar to those whereby the volcanoes of the great American chain have their maximum intensities at different periods, and it is possible to explain the phenomena by reference to the existence of subterranean lava lakes.

384. Hypothesis of Connection between Sea and Volcanic Centres.—It has been already more than once remarked that the majority of volcanoes are in the vicinity of the ocean, Jorullo, in Mexico, being but an apparent exception, since it seems to be a member of a chain, the great part of which is certainly close to the shore. The volcanoes in the Caucasus are distant indeed from the ocean, but close to the borders of the Caspian Sea. The constancy of this relation has suggested the probability of water being the principal agent by which volcanic activity is called into operation. The passage of water downwards into the volcanic foci, seems to have the effect of calling into fresh activity those chemical changes by which heat is evolved, and, as a consequence, the expansive power of vapours is increased, and even the solids themselves come to occupy a larger cubic space. Common salt has been obtained from the fumes of Vesuvius—is even thickly deposited with other chlorides after eruptions. Hydrogen is known to escape from volcanoes, although its flame is not readily detected amidst the more powerful light of red-hot cinders. In its discharge and conversion into water when burnt in the open air, we find one explanation at least of the steam which constantly occurs in eruptions. The absence of magnesia, which seems a difficulty in the way of this theory, is explicable by the circumstance that the chloride of magnesium is decomposed into hydrochloric acid and magnesia, the latter coming to form a very important constituent of lava (Art. 366). That materials from the the surface have been introduced is well known from the fact that Vesuvius has ejected, from time to time, infusorial cases amongst the ash, these animal remains having obviously reached the interior by fissures of some sort. It is not quite so easy to understand the source of the nitrogen which is obtained from the craters of active volcanoes, and is observed in the waters of thermal springs. Perhaps the only plausible explanation of its occurrence is that, as the columns of molten matter and of heated water surge upwards and downwards in the supply pipe, the vacuum created by their sudden retirement becomes filled with air, which ultimately reaches the interior. It is not altogether out of place to recall the suggestion put forward by Sir Charles Lyell, that the loss of heat which the earth is known to sustain may be replaced in some measure by electro-magnetic force from the sun. It is defended by him on the ground that, although it may appear like an attempt to establish perpetual motion, our knowledge does not yet permit us to be content with an epigrammatic condemnation of the suggestion, since farther knowledge might prove the possibility of the hypothesis, just as observation has established the unexpected fact that the radiation of heat is retarded by atmospheric moisture. It must of course be remembered that the tendency of all chemical change is towards equilibrium, and that equilibrium must ultimately be arrived at, further change being thereafter impossible without the introduction of fresh material, or the disruptive action of some force different in its manifestations from that of ordinary chemical combination. The only question of any importance is as to the rate at which we are tending towards equilibrium, as to the rate therefore at which it is probable physical and organic changes went on in the past; and on this problem we are scarcely yet in a condition to speculate profitably.

385. Vapour and Thermal Springs.—It has been mentioned that some volcanoes, as those of the Andes, emit lava comparatively rarely, and chiefly give escape to ashes and vapours. One step more brings us to those orifices from which steam alone, or hot water alone, or gaseous vapours alone are discharged, a solid material, even in the form of fine ashes, never accompanying the emission. To this group belong the geysers, or hot springs of Iceland, of the extinct volcano of Ischia, of the island of St. Paul's, and many other localities which are obviously directly associated with volcanic activity, either in the past or the present; second, the solfataras, from which sulphurous vapours alone are emitted, these being either on the volcanic cone or near it, or, as sometimes happens, at considerable distances from craters active or extinct; third, fumaroles, from which boracic acid is discharged; fourth, naphtha; or, fifth, carbonic acid vapour. To the same category belong the sulphurous, siliceous, and gypseous springs in various regions, as in Yellowstone Park (Art. 160), Savoy, and Germany, where, at least within recent geological times, no volcanic activity has been manifested. Chemically, the substances found in these springs and lakes are identical with those obtained from volcanoes; and although it might be difficult to establish by direct proof the actual connection between all these kinds of phenomena, still the probabilities are in favour of, at least, the community of their origin.

386. Intermission of Geysers.—A very interesting physical problem is associated with the intermittence of the Icelandic geysers, and Tyndall has given a satisfactory explanation of it, and an illustration by a simple experiment. He carried down a metal tube from the centre of a basin full of water, and surrounded the bottom of the tube, as well as a part of its length, with a ring of fire. The water being thus subjected to a considerable heat at two points, he procured eruptions of hot water and steam at irregular intervals of five minutes; for the water at the bottom, becoming heated, expanded and lifted the water above it for a certain distance. Relieved to some extent of pressure, and its boiling point thus lowered (as in passing from thirty-eight to thirty-two feet), it expanded into steam, and the heat evolved in the process generating steam in the mass beneath, the whole suddenly burst into ebullition and propelled the superincumbent mass out of the tube. It fell back chilled into the basin, descended again into the tube, and the process went on again until the temperature of the whole mass was sufficiently raised to permit of another explosion. The application of this experiment to the geysers relieves us of the necessity of imagining underground caverns containing water and steam, and restricts the mechanical production of the phenomena to the heating of the fissure through which the spring rises. In the subjoined table the boiling temperatures are those at which water should boil at that depth and pressure : the observed temperatures are the actual ones ascertained by Bunsen in the tube of the great geyser, and these are below the boiling point; it is obvious that the water must be raised in the tube before it can pass into steam.

Observed Temperature.	Feet.	Boiling Temperature.
85·5° C.	6	107° C.
110°	22	116°
...	32	120·8°
121·8°	38	123·8°
124°	50	130°
126°	64	136

Of the effects produced by these and other springs, which contribute solid matter to the sedimentary strata, enough has been said in a previous chapter when treating of springs.

387. Periodicity of Earthquakes and Volcanoes.—It only remains to speak of the periodicity which, it is alleged, may be observed in earthquake and volcanic phenomena. That tolerably equal intervals have been noted, as the thirteen year periods of Icelandic disturbances, is true; but the rarity of such observations, when taken in conjunction with the much better observed irregularity of the events in other regions, makes it probable that the supposed periodicity rests upon coincidences. The history of Vesuvius, as given by Professor Phillips, and of Etna, does not bear out any periodicity of either, or even any regularity of their alternations. Only one observation seems to suggest the possibility of external influences securing regularity in the phenomena, namely, that the great majority of volcanic eruptions have taken place in winter. M. Perrey believes that there is a greater amount of activity when the moon is nearest the earth, and when the earth is in perihelion. If a sufficient number of observations, sufficiently authenticated, should confirm this suggestion, a certain amount of periodicity might be traceable to these astronomical influences; but in the meantime the data are insufficient to warrant the general conclusion, which is scarcely reconcilable with the teaching of physicists regarding the effects of tides in the earth's interior.

388. Secular Movements of the Earth's Crust.—Intimately associated with this subject is that of slow elevations and subsidences. It is known that rocks undergo a certain change of dimension in passing from the fluid to the solid state. The estimates of the amount of this change vary considerably; thus Bischof's calculations make it appear that granite suffers a diminution in volume of twenty-five per cent. in passing from the fluid to the crystalline condition, while Delesse calculates that the contraction is only nine to ten per cent. These materials, however, occupy a comparatively small part of the earth's crust, while the sandstone, upon which extensive observations have been made, are more important as regards their mass, and, therefore, as regards the influence they may perchance have. Lyell calculates that, according to the data given by the experiments of Totten on building stones, a mass of sandstone a mile in thickness would, if raised to a temperature of 93·3° C., lift the rock above to a height of ten feet, while the heating of a mass fifty miles in thickness to a temperature of 315° or 426° might yield an elevation of 1000 or 1500 feet, the subsequent cooling producing a corresponding amount of depression. The contraction, again, of clay rocks under the influence of high temperature might yield subsidence. Taking this in conjunction with the supposed falling in of the roofs of subterranean chambers, we have, in the volcanic foci, an adequate cause at once for the violent and the slower variations of level at the surface; while, as has already been suggested, the percolations of springs below ground may likewise, by the removal of soluble rocks, lead to depressions on the smaller scale.

It is alleged that the globe is still undergoing contraction, and that the elevation of mountain chains is attributable to this cause, which also takes share in the production of volcanic outbursts. But it is difficult to adopt this view, for we have abundant evidence of repeated elevations and subsidences in the same area at very different periods, and to very unequal amounts. Africa, though a continent for an immense period, has no great mountain chains such as this theory would require, and some of the oldest mountain chains have not that enormous height which their antiquity might be expected to involve, while the highest chains are those of most recent date. It must on the other hand be remembered that the great ocean basins are of great antiquity, and that, while subordinate movements have occurred in abundance, the geological record only tells of one grand alternation, that whereby the Atlantic and Pacific, once land, have become sea, while land has taken the place of the former great oceans.

CHAPTER IX.

DISTRIBUTION OF PLANTS AND ANIMALS.

Fauna and Flora: Aspects of Life—Relation of Existing to Former Faunas and Floras—Aspect or Facies of a Region: How Determined—Laws of Distribution—Non-coincidence of Botanical and Zoological Provinces—Aquatic and Subaërial Animals: Not Essentially Different—Influence of Climate—Parallel Regions in Latitude and Altitude—Marine Bathymetrical Zones—Provinces Determined by Physical Conditions—Specific Centres—Biological Provinces Unequal—Sclater's Provinces: Neotropical; Ethiopian; Indian; Australian; Palæarctic—Common Character of Neotropical, Ethiopian, Indian, and Australian Provinces—Analogous or Representative Forms—Migration of Species and Extension of Area—Results of Migration—Natural and Artificial Selection: Survival of Fittest—Variations: How Beneficial—Mimicry: Protective and Independent Resemblances—Representative Species—Dangers Incident to Migration—Tabular View of Organic World—Homotaxis—Insular Faunas and Floras—Hypothesis of Lost Continents—Marine Provinces: N. Atlantic; Caribbean; Indo-Pacific; Australian; Western S. America—Pelagic Forms—Deep-sea Faunas—Continuity of the Cretaceous Epoch—Extension and Replacement of Species—Persistent Types—Progressive Development.

389. Fauna and Flora: Aspect of Life.—The animals which inhabit any area constitute its fauna; the plants constitute its flora: and these terms are equally applicable to the inhabitants of contiguous or of distant areas. They are, in fact, quantitative terms, while the qualitative comparison of these faunas and floras shows that there are differences which give to each fauna and flora its *aspect* or *facies*. The aspects may be identical in closely-contiguous areas, utterly unlike when distant areas under dissimilar conditions are compared, or representative of each other in the case of distant localities under similar conditions. It has already been stated that the provinces of the earth at the present day are the same in kind as the provinces of former periods. The comparison of the faunas and floras of the past with those of the present shows that the plants and animals of the present are very closely allied to, if not identical with, those which flourished in the most recent times over the same area; that the difference between the existing and former faunas and floras increases the further back we go, and that the organic forms in one locality at one period frequently strongly resemble those of another locality at another period.

390. Relation of Existing to Former Faunas and Floras.—The fact that the most recent fossils are of the same genera, or even species, as the living beings is clearest where, as in South America and Australia, the characteristic forms are restricted within narrower limits. The gravel and cave bones are of marsupials in the one case, of sloths or their allies in the other; but equally good, though less-striking, examples are to be found in every country. The wealden fauna and flora are very unlike those of Europe now; but there are points of resemblance to those of Australia; and it may be said, in general terms, that the mesozoic animals have an aspect to which at the present time the Australian area offers the only resemblance. Principal Dawson has shown that the pre-carboniferous flora of N. America has greater affinity to the secondary flora of Europe than to the carboniferous or subsequent floras of America. But it must be remembered that in plants the non-preservation of the parts essential for safe classification, these being usually of very soft tissues, places great difficulty in the way of this systematist, and renders his conclusions imperfect and insecure.

391. Aspect or Facies of a Region: How Determined.—From what has been said in earlier chapters it is plain that the modifications in texture or composition of rocks must be great before they can give rise to marked differences between two countries which have been subjected to precisely similar influences. The physical aspect, therefore, results from a smaller number of factors than the organic. But while the practised eye may gather the main points in the geological history of a country during a rapid visit, general impressions do not count for much as regards the life of a country. Brilliant descriptions of tropical vegetation, after all, teach little except the well-known fact that great heat favours another kind of vegetation than that found in temperate or, still more, in cold regions; or the generalization may be extended to this, that endogenous plants are more prominent than exogenous in the tropics. But if by facies or aspect is meant, not the obvious features merely, but those which give individuality to particular regions, we find that here, as in the domain of physics, some standard more reliable than that of the senses must be appealed to. The following table, given by Pokorny, shows how changing is the statistical guide, even in the case of plants, which are, in one way, more easily obtained and enumerated than animals:—

Linnæus	enumerated in	1754,	about	7728	species
Persoon	,,	1801,	,,	21,000	,,
Sprengel	,,	1828,	,,	36,000	,,
Stendel	,,	1840,	,,	87,000	,,
Unger	,,	1852	,,	92,662	,,

In 1859, the number of species was variously estimated, according to Hooker, at 80,000, and 150,000 according to the opinion of the systematist as to what constitutes a species. And this source of difficulty increases with the number of new forms observed in new localities explored.

But these numbers do not, after all, represent a fair summary of the whole earth. Some regions are as little known as others have been exhaustively investigated; and this is still more true for the animal kingdom. The lists of fossils, necessarily incomplete for any region, since we have not exhausted, and never shall exhaust, the contents of its rocks, are for most countries fragmentary, while in many the exploration can scarcely be said to have commenced. If, therefore, the aspect of the life of any region at any period helps us to trace out its geographical history, we must qualify our conclusions by the recollection of our imperfect knowledge, and, setting aside our impressions, trust only to careful enumerations of all the species that have been recorded. It is a common impression that a group of animals tells by simple inspection its native place: but, in reality, the judgment is based, not on the impression conveyed by the whole, but on the rapid recognition of the individual species which make up the group.

392. Laws of Distribution.—The facts as to the presence or absence, the luxuriance or insignificance, of species, genera, or families, in particular regions, and the conditions of temperature and the like which these regions present, have been embodied in propositions which are spoken of as the laws of distribution. The phrase is an unfortunate one, since it suggests too great a value for the results of experience in this branch of science. All laws are, in one sense, the fruit of experience, and their experimental verification is the test of their scientific value, for they can be received as laws only if they enable us to announce what is past, and to anticipate the future. The law of the attraction of bodies is so exact as to lead to the recognition of the exsistence of planets, before they have been seen, the influence of gravitation being determinable at any point in the orbit of a planet. The mechanical theory of heat enabled James Thomson and Magnus to arrive simultaneously at the conclusion that the freezing point might be lowered by pressure, and the experimental verification of this opinion proved it to be an accurate deduction from an exact generalization, a *law* in the scientific sense of the word. The constant sequence of phenomena in these two cases is, so far as our knowledge and experiments go, uninterrupted; but the *necessary* connection between the antecedents and consequents in any phenomenon, that peculiarity of the things which makes their relation to others not merely invariable but inevitable, it is impossible for us to ascertain. But while the phenomena of the inorganic world manifest the nearest approach to absolute certainty with which experience makes us acquainted, those of the organic world display an uncertainty which increases with their complexity, or, to use more precise language, their sequence is obscured by the number of contending influences. There is no law operative in the inorganic world which is not also operative in the organic; but as the tissues which make up an organised body are multiplied, their proportions vary, and the preponderance of particular parts undergoes change. Hence the sequence of phenomena, which by analogy we are assured must be normal, is concealed, because we cannot isolate events. Our estimates, therefore, of the power of any one kind of influence on an organised body, are only reliable in proportion to the number of instances on which they are based; for it is only by multiplying the cases that we can diminish the chances of error. The theory of probabilities teaches that a certain event must recur in a certain number of trials, when we know the number of contingencies upon which it depends; but in the organic world the number of contingencies is not and cannot be known, so that a generalization based on 1000 instances may be at variance with the next instance, the details of which are unknown and cannot be foreseen. And if this is true for any one physiological process, the results of which are compared in 1000 individuals, it must be true also for the sum of the processes which take place in 1000 individuals. The external influences to which organic beings are subjected are comparatively few in number and kind; but the internal modifying influences are indefinite in number and variable in kind. In previous chapters it has been shown that these external influences are perpetually changing; the multiplication of instances, therefore, is of itself apt to multiply the chances of error, since, if they are taken over a wide range in space or in time, the introduction of new influences is more probable. Now, as plants and animals are in themselves thus variable, and as the external influences are likewise liable to change, any general proposition regarding the distribution of organic beings is true only for the cases that have been observed. It is not, and cannot be, a law, as that word has already been defined, for it cannot make us sure that the like has happened in the past or will in the future. The distribution of the elephant at the present time would not lead us to expect that the remains of any member of that genus should be found in Britain or Siberia, still less would the characters of existing genera have led us to believe that any members of the family had been protected by a hairy covering. If it is impossible to assign a higher value than that of a careful summary of facts to the results of our comparison of many individuals, or groups of individuals, *i.e.*, classifications, it is still less possible to attach greater importance to the results of comparison of the faunas and floras of different regions, *i.e.*, botanical and zoological geography. The antecedents in many cases are connected with the consequents in a way which it is impossible for us to understand; thus we say that increase or diminution of temperature has driven out the animals of a region, but we cannot frame an explanation of the way in which heat or cold affects an animal or vegetable, so that the difference of a few degrees in the annual average may render a country favourable to it, or the reverse.

393. Non-coincidence of Botanical and Zoological Provinces.—Botanical and zoological geography do not coincide: the natural provinces of the one or other kind of life have different limits and centres, as might be expected, when we consider their different physiological endowments and susceptibility to external influence.

394. Aquatic and Subaërial Provinces.—The most obvious distinction of distributional areas is that of aquatic and subaërial, and the aquatic forms are restricted to fresh or salt water, to lakes or rivers. But the difference between gills and lungs is more of form than essence: in the one case the oxygen is held in suspension in the water; in the other it is in mass in the atmosphere. The distinction between aquatic and subaërial animals, though greater than that between aquatic and subaërial plants, is after all less than is commonly supposed; for in both cases the gas passes through membrane to reach the circulating blood, and the temperature of the animal is in proportion to the amount of air absorbed, which is least where the water flows over the membranous projections covering blood-vessels, and increasingly greater where the air is received into membranous sacs, on the outside of which the vessels are distributed. The possession of gills is permanent or temporary in the life of the individual; thus the fish is aquatic throughout life, but in the groups of amphibians some retain gills permanently, others speedly lose the gills and acquire lung sacs; while in a third group both organs are present, and are alternately used as the necessity arises.

395. Climate.—If vital phenomena were as limited in their range as are inorganic, or, in common phrase, physical processes, the isothermal lines might be expected to correspond more or less closely to the limits of larger or smaller groups. The correspondence is, however, not very exact, since physical features, affecting atmospheric and oceanic currents, cause local variations from the normal temperature, or that proper to the latitude; but more striking is the want of correspondence when the seasonal temperatures are considered in place of the mean annual temperatures. Thus the annual migrations of birds, as of the swallows from the south, the fieldfares from the north, into our own area, are examples of the uncertain limits which average temperature imposes on distribution. But, besides these extreme cases, inspection of the maps of distribution shows that the same species may have very wide limits, passing through several zones of temperature; thus the bison and Virginian opossum range from Canada to the Mexican Gulf. The tailless hare and the tiger extend from about 55° N. lat. as far south as Java, but their range to east and west is restricted. This absence of animals from adjacent regions under the same conditions is one of the reasons for assigning to climate a subordinate influence in distribution.

396. Parallel Regions in Latitude and Altitude.—Ascending a mountain under the equator brings the traveller into successive belts of temperature, which repeat the experience of one passing towards the poles, and as each zone in latitude has a characteristic aspect of life, so have the corresponding belts in altitude; the snow line is the limit of abundant life in both cases. The following are the zones of distribution of plants useful to man:*—

Zone.	Approximate Latitudes.	Characteristics.
Tropical, ...	0° to 23° 30′	Rice, maize, palms, spices, sugar.
Subtropical or warm temperate, . .	23° 30′ to 45°	Wheat and tropical grains. Olive, fig, grape, citron.
Temperate, . . .	45° to 55°	Wheat and northern grains. Orchard fruits, deciduous leaved trees.
Subarctic, . . .	55° to 66° 30′	Northern grains. Berries, pines.
Arctic, ...	66° 30′ to 90°	Saxifrage, mosses, lichens.

The eight zones tabulated by Meyen give undue importance to mere temperature, and are therefore artificial in their construction, as well as arbitrary in their grouping, of the plants in each. The zones in altitude corresponding to these horizontal areas are shown on the figure, *Student's Physical Atlas*, Map XVIII., and their temperate limits are better founded. They are, in ascending order, the regions of—(1), bananas and palms on the low grounds; (2), tree-ferns and figs, up to 2020 ft.; (3), of myrtles and laurels, 4050 ft.; (4), of evergreen dicotyledonous trees, 6120 ft.; (5), of European dicotyledonous trees, 8100 ft.; (6), of pines, 10,140 ft.; (7), of rhododendrons, 12,150 ft.; (8), of Alpine plants, 14,170 ft.; (9), the plantless region, commencing with the snow line, 16,200 ft. The correspondence of these two kinds of zones is not, of course, exact; but the agreement is in keeping with what has been already said (Art. 207) of the shells of temperature with which the earth may be regarded as surrounded.

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* Yeats.

397. Marine Provinces: Bathymetrical Zones.—The areas of distribution in the sea are less distinct in climatal demarcation than those of land, the temperature being more uniform. The belts distinuished by Professor E. Forbes are, therefore, purely topographical, and approximately correct for every region, representative forms occupying corresponding positions. The five bathymetrical areas are: 1. The littoral zone, between tide marks, or at the water's edge in tideless seas. 2. The circum-littoral zone, from low tide to 15 fathoms. 3. The median zone, from 15 to 50 fathoms. 4. The infra-median, from 50 to 100 fathoms. 5. The abyssal zone, from 100 fathoms downwards. Since it is now known that life descends to the bottom of the ocean, the fifth zone may yet be subdivided, but the data are in the meanwhile imperfect.

398. Provinces Determined by Physical Conditions.—The influence of temperature is controlled by the physical features of the land above and below water. A mountain chain, such as the Andes, is an insuperable barrier to the passage of plants or animals. The deserts of Africa separate regions as sharply as does the sea. In the sea, where a superficial view might lead us to expect great uniformity, there are provinces recognisable, though their demarcation is not always clear. But a current may be a bar as absolute as a mountain range, and a deep central trough, as that of the Atlantic, seems as effectual a means of separation as a desert. In the N. Atlantic basin warm and cold areas were described as connected with the features of the sea bottom (Arts. 75-85), and by their interlacement the faunas of northern and southern regions are found under the same parallels. Among the anomalies of distribution must be mentioned the absence of animals from an adjacent area from which they are separated by obstacles seemingly out of proportion to the result. Thus the distinctness of Madagascar from Africa, and of the two parts of the Malayan Archipelago, even of Ireland from Great Britain, leads us to what is the primary cause of the features of the botanical and zoological geography at the present time.

399. Specific Centres.—Plants and animals are grouped under species, and these under genera; these again under families, orders, classes. The number of species included under a genus varies, and the number of varieties under a species is likewise unequal. But the proportions in both cases have reference to the extent of country they cover, and to the variety of its surface. There is little variety in the animals of a country which, like Africa, is remarkable for uniformity; on the other hand, the changes of conditions presented by such a region as the Amazon valley are associated with the presence of many local varieties among the butterflies, as Mr. Bates has described. Though they do not prove, these two converse facts support the view, that species are modified as they spread from the area or centre in which they first appeared. It is now accepted as indisputable, that species which have become extinct, do not recur in the geological series, and the forms which have descended almost unchanged from remote times to the present confirm us in the belief that continuity of descent is inseparable from continuity of character. The isolation of specific or generic types at the present time is, therefore, explicable by reference to the geographical changes which have been described in previous chapters of this volume. It is beyond the scope of such a book as this to discuss the question of the origin of species; but the view here adopted is, that species are developed out of other species by modification. Considerable difference of opinion exists as to the nature of the processes by which this modification is accomplished;

but the theory affords the only means of co-ordinating a mass of facts which no other doctrine yet proposed has brought into harmony. To physical changes, therefore, must be assigned the primary influence in bringing about the distribution of organic forms such as we now see.

400. Biological Provinces Unequal.—Reference has been made in previous paragraphs to the unequal plasticity of organised forms, to the unequal power they possess of enduring vicissitudes in the conditions to which they are subjected. It may be said in general terms that this power of endurance is in proportion to the simplicity of the organism; that the simplest forms are those which have the widest range in space, and have had the longest existence in time. As the complexity of an organism increases, its power of endurance diminishes, as a rule, in the same proportion; so that the continued existence of its offspring depends upon their capacity to change at the same rate as the conditions alter. If the capacity is limited, extinction of the type must ensue. If the capacity is great, or if the external changes are slow, the modification gives rise to new species. In some groups, both of plants and animals, the changes in a given time must be greater than in others, and after long intervals the specific centres, say of the grasses or of the molluscs, must have undergone considerable change of position. A series of maps, each devoted to the distribution of a distinct species or genus, would present very great differences, the amount of which may be inferred from the comparison of those given in Mr. A. Murray's *Distribution of Mammals*, 1866. But while the centres of maximum development of animal and vegetable species do not coincide, there is sufficient agreement to render possible the division of the earth into regions, each of which is characterised by the presence of an assemblage of plants and animals whose association has reference to the previous geographical conditions of the areas.

401. Sclater's Provinces. — The provinces, which thus harmonize biological and geographical changes, are those first set forth by Dr. Sclater for the birds, and since approved by Mr. Wallace for the animal kingdom generally, while they include tolerably well the main facts as to the distribution of plants.

Regions.	Areas.
1. Neotropical, .	South America, Mexico, West Indies.
2. Nearctic, . .	The rest of America.
3. Palæarctic, .	Europe; Asia, north of the Himalayas, as far as Japan; Africa, north of the Sahara.
4. Ethiopian, . .	The rest of Africa; Madagascar.
5. Indian, . . .	Southern Asia; west half of the Malayan Archipelago.
6. Australian, .	East half of Malayan Archipelago; Australia; and most of the Pacific Islands.

402. Neotropical Region.—South America contains, as its characteristic animal forms, the platyrhine monkeys, which are distinguished from the Old World forms by the thicker septum between the nostrils, and by the possession of 36 not 32 teeth. The antiquity of the province is shown by the exclusive presence in the tertiary deposits of monkeys belonging to this type, no member of the Old World group having been discovered. The sloths and armadilloes are similarly related to their predecessors, the megatherium, glyptodon, and the like, and Mr. Bates regards the arboreal habit of the sloth as acquired during long residence in a wooded country. The llama, alpaca, and guanaco, form a characteristic group confined to the higher plains of the eastern slopes of the continent, while the vampire bats are also confined entirely to this region.

403. Ethiopian Region.—The submersion of the Sahara down to tertiary times, formed a barrier which helps to explain the separation of the north coast of Africa from its tropical and southern districts, and the specific distinctness of its elephant, of its three species of rhinoceros, and the restriction to it of the hippopotamus. The chimpanzee and gorilla are the anthropoid apes of this region, while the lower groups are numerous, but all belong to the catarrhine division. Madagascar, separated from Africa by the Mozambique Channel, contains very few mammals common to it and the continent (Art. 419). The characteristic lemurs have been found fossil in Europe, and the difference between two countries so near, and placed under similar climatal conditions, indicates the antiquity of their separation.

404. Indian Region.—The eastern boundary of this area, the strait between Borneo and Bali on the one hand, Celebes and Lombok on the other, is only fifteen miles broad, but its depth is greater than 100 fathoms, and this corresponds to a geographical separation of great antiquity. The western boundary is less definite geographically, the Ethiopian and Indian types being mingled on the continental land surface of Arabia. The scitamineæ, zingiberaceæ, and bananas are the most characteristic forms of plants, and the fitness of local climates for certain species of food plants from other regions, has been experimentally proved. The elephant, tapir, and rhinoceros are wide spread over the area, and the species of ox (*Bos gaurus* and *B. gavialis*), though kindred to the S. African species, have remarkably local areas. The reptiles of the Indian area are well defined, the exceptional occurrence of tropical snakes in Japan, and of a few tropical butterflies, telling of a former southern land connection of Japan, whereby these Indian forms gained a footing among a mass of palæarctic species. They represent groups which otherwise would have been unrepresented, and their continuance looks like the fulfilment of a function in nature.

405. Australian Region.—But though mammals, birds, and reptiles agree in defining the Indian region by the Straits of Lombok, the insects wander over the line on both sides, the mixture of species being here due to power of flight, as in Arabia it was due to absence of obstacles. The other groups of animals leave no doubt as to the definiteness of the Australian region. The marsupials, and the absence of placental mammals, are the leading features of the greater portion of the land. Among birds, the emu, mound-building megapodius, the honey-suckers, and loris, form a characteristic assemblage, while the kivi or apteryx still represents the struthious birds, of which the moa was the last survivor, having become extinct probably within the last century. The gum trees, eucalypti, heaths, epacrides, the proteaceæ, casuarinas, and gummiferous acacias are among the most characteristic for the continent, but the variety of climate which different portions of its borders offer, is accompanied by local peculiarities in the grouping of the plants. The grass plains of the interior are like those of the north temperate zone; the scrub is peculiar, since no turf accompanies it, and the heath-like, vertically placed leaves offer little protection to the soil beneath. The combination of American, Australian, and Antarctic plants in New Zealand, the latter being confined to the high ground, renders it probable that the present aspect of the vegetation was acquired after many great changes of the geography of the South Pacific, and after the dispersive influence of a southern glacial epoch had been felt.

406. Palæarctic Region.—The Europeo-Asiatic continent from Japan to Spain, and to the north of a line from the Atlas through the north of Arabia and the Himalayas, presents a singular uniformity in the distribution of mammals, 76 per cent. of European species being common to Amoorland, while Algeria contains forty-seven species and about twenty-eight genera common to the lands north and east of the Mediterranean. There is a similar agreement as regards the other groups of vertebrates, with the exception of the Japanese serpents, which are tropical. The land molluscs agree, on the whole, with the vertebrates; and the plants likewise render this a natural province, save in the eastern Asiatic region, in which American affinities indicate relationship to the miocene flora.

407. Common Character of Neotropical, Ethiopian, Indian, and Australian Regions.—The bird fauna of the great area thus included is of great interest. To these regions are confined the struthious birds, including the ostrich of Africa, emu and apteryx of Australia, cassowary of the Malayan group, rhea of America. The edentates, including the sloths and armadilloes of America, the pangolin of Africa and Malaya, and the orycteropus of Africa are confined to this area; while the anthropoid apes range from Eastern India to the west of the Ethiopian region. The tapir is American and Indian, the elephant Ethiopian and Indian, the marsupials American and Australian. To this must be added the common characters of the plants of S. America, S. Africa, and Australia, which, though not comparable in importance with the zoological resemblances just stated, contribute to the evidence in favour of a former connection between these different land masses in the southern hemisphere, though the connection was not simultaneous. Oscillations of land, such as the coral islands show to be still going on in that region, formed at various periods bridges between the different areas, and it is probable that some of these connections date from the triassic times, when S. Africa assumed the continental form which it has since retained.

408. Analogous or Representative Forms.—A distinction must be observed between these common types and what are known as representative forms. As a general rule, the habits of species under the same genus are closely similar, if not identical, the affinity of structure which constitutes them members of the same group offering a presumption in favour of such resemblance. Thus, the elephants of Asia and Africa are equivalent, so far as their share in the economy of nature is concerned. The llama and its kindred, again, represent the camel, but are not equivalent to it. These relations are consequent on the diffusion of the descendants from a common stock, the forms, divergent in their migrations as well as in their structure, being dissimilar also in habits according to the character of their new surroundings; but the departure stops short of that utter difference which would be associated with changes so extreme as to efface even the family resemblance. But another kind of resemblance, for which analogy is the best term, exists between members of distinct orders. Thus the marsupials present, within the limits of that group, most of the habits and corresponding modifications of form which occur among the placental mammals. The carnivore has its analogue in the thylacinus, the ruminant in the kangaroo, the insectivore in the myrmecobius. This remarkable parallelism is due to the long occupation by the marsupials of their isolated territory, and to the consequent competition among them, resulting in the adaptive change which has specialized each group by its mode of life..

409. Migration of Species, and Extension of Area.—Every species tends to spread in all directions as the number of individuals increases; and if the conditions are similar on all sides the spread will be equal, an event which can rarely happen. But this extension of area must be distinguished from transfer of the point of maximum development. This takes place—

a. When climatal changes occur. All species are not equally capable of migration, hence extinction in the primary locality may go along with increase of numbers on the margins of the area, while expulsion in mass will shift the area of the more locomotive species. The glacial period was the climax of a series of migrations whose progress is traced in the changes of the pliocene faunas.

b. When geographical changes occur. But as there is every reason to believe that these are, on the whole, gradual, the changes are more likely to have been by migration, and expansion on the margins of the specific area, than by extinction in one locality.

c. When the food supply of a species alters. Whatever affects the vegetation of a district must affect, however slightly, all the inhabitants of that district. Any disturbance of the balance, say by the failure of one kind of plant, will to that extent alter the diet of the graminivorous mammals, while space will be left for the free development of other kinds, or their importation from elsewhere; and importation of new plants usually brings new animals, whether their influence be important or not. The annual migrations of animals, commonly referred to instinct, are, in many cases, rather due to appetite. Their occurrence at the time of seasonal change has led them to be referred to climatal causes. But the migration of the swallow southward at the close of the summer is towards a region where he will find during winter abundant insect food, wanting in that he has quitted. The bison travels after the food which he exhausts in each successive locality by destruction as well as consumption; and the herds have their return timed by the renewal of the herbage. The quest of water leads to other great migrations, and these movements, of irregular periods, are identical in kind with those which, from analogy, may be assumed to have some share in this shifting of species.

d. When enemies or competitors appear or disappear. The vegetation of New Zealand seemed that best adapted for the country, but its development was due to long isolation; for, where European plants were imported, the white clover is displacing the ferns and native grasses; the cow-grass (*Polygonum aviculare*) follows all the road lines; the dock (*Rumex* under some influences whose operation we know nothing of, it is immaterial here to discuss. Suffice it that these changes will be perpetuated if they are beneficial to the animal; that just as particular varieties are "selected" artificially by man, so in nature a stronger or better endowed animal is selected, and survives and multiplies, its weaker or worse endowed associates disappearing. Continuing to use the impersonal language hitherto employed, the illustration taken by Mr. Huxley is a happy one, when he says that the wind selects the successively finer sand on the dunes, and that frost selects the weak plants as the gardener would select them.

413. Variations: How Beneficial. — The modifications which constitute "the fittest," may be either of an obviously useful kind, as the length of neck which extends the giraffe's browsing ground, the length of limb which increases the swiftness of a carnivore, or which gives its prey better chance of escape. In artificial selection that may be desirable which to the wild animal would be fatal, as the shortness of limb which gave to the Ancon sheep of Massachusetts their value, because they could not leap fences. But the benefit may be indirect, as when a beetle (*Psox*) has the colour and appearance of dust, and thus escapes detection; when a leaf—or a stick—insect is indistinguishable from the vegetable matter amid which it lives; when one butterfly comes to resemble a butterfly of another species, so as to acquire the immunity from the pursuit of birds enjoyed by that one which it resembles; or when a moth and a humming bird have a superficial likeness protective to both.

414. Mimicry: Protective Resemblances: Independent Resemblances.—All these modifications are in reality unconscious on the part of the animals, though the poverty of language renders it difficult to avoid the suggestion of volition in the last-mentioned cases. But the occurrence of resemblances which cannot be protective, demonstrates the unconscious character of the change, and points to similarity of endowment of living bodies as the source of the accidental similarity which is seen, for example, in the curious likeness of marine shells in one part of the world, to land shells in another. Homogenetic has been proposed for resemblances which may be traced to common ancestry, homoplastic for changes produced by similar influences on similarly endowed tissues.

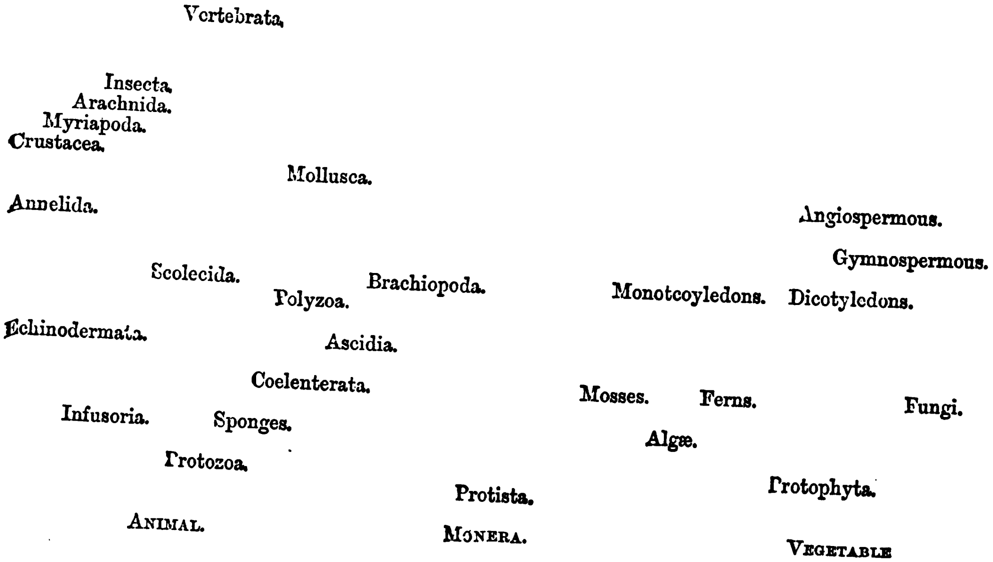
415. Representative Species.—In distant regions identical forms are met with, the more frequently the lower are the organisms, wide distribution in space and time being proportioned to the simplicity of the forms. But among the higher plants and animals, the independent origin in both localities of the identical forms is rendered improbable when it is found that, in the one case, the individuals are so numerous as to indicate that this is their proper habitat, while, in the other, their paucity indicates that they are outliers, and sometimes the intervening area may yield fossils proving the former continuity of the species. Moreover, on the assumption that all species reach their present localities by migration, the improbability of identical variations occurring far apart is very great, since the influences cannot be absolutely identical, and perfect reversion is unknown. But closely allied forms may arise, and these are truly representative species, since they set forth the changes produced by similar conditions in the descendants from a common stock.

416. Dangers Incident to Migration. — The diminishing number of the travellers might be expected, when it is remembered that every change of locality may yield change of temperature, of food, of rivals, and of enemies. The prospect, therefore, of great extension of a species, and of its numerical superiority, is a complicated problem, to which must be added another factor, the number of individuals which may have started on the route.

The names in the following table must be regarded as the ends of branches which are given off successively from previous branches. It is not necessary in this volume to state the points of divergence. It is only desired to suggest that the succession is no more linear than is that of the branches of a tree, the highest branches of which diverge from the axis equally with the lowest.

417. Homotaxis.—It is often said that, in the silurian times, there was a greater uniformity of life over the earth than there is now, the deposits of that epoch, wherever examined, revealing closely similar forms. But all strata are assumed to be silurian which are the earliest fossiliferous

TABULAR VIEW OF ANIMAL AND VEGETABLE GROUPS.



strata of each region, an arbitrary basis is assumed, and the resemblance of these rocks in different regions is exaggerated, it being forgotten that as these strata everywhere rest on metamorphic rocks (where their lowest portions are visible), it is impossible to say to what extent the records of pre-existent zoological provinces have been destroyed. In later deposits, as the marine portions of the carboniferous series, community of fossils in distant localities has been taken to indicate contemporaneity of deposits, and the existence of identical species at the same time in these localities. Reasoning from the small number of identical species at distant localities at present, and from our imperfect knowledge of the strata whose organic contents are said to be identical, the opinion first announced by Godwin Austen seems correct, that identity of species indicates lapse of time sufficient to have admitted of migration from one locality to another. Professor Huxley proposed the term homotaxis as expressive of the relation of such fossil groups, insisting that strata, characterised by similar remains, show a similar but not identical sequence in each locality; and this doctrine, that geological formations represent geographical provinces rather than periods of time, is in accordance with Professor Ramsay's investigations into the distribution of former continental areas.

418. **Insular Faunas and Floras.**—In an earlier chapter the population of islands was said to differ from that of adjacent lands in proportion to the antiquity of its isolation. The Atlantic islands illustrate this generalisation. The Madeira, Çanary, and Cape Verde groups differ from the mainland and from each other. There are no indigenous mammals except bats; but such quadrupeds as have been introduced prosper remarkably. Madeira has, on the other hand, ninety-nine species of birds, of which one is peculiar, two are common to it and the Canaries, the rest are European; and it is noticeable that the number of these is greater on the eastern than on the western islands, the wind-driven birds first alighting on the eastern. Every island seems to have its own peculiar insect forms, two-thirds of the Madeira beetles being as yet unknown elsewhere. The flora of these islands has the same American aspect as the miocene flora.

of central Europe, and it is probable that this resemblance is due to the transport, from adjacent miocene land to these islands, of seeds which might be carried by birds or drift wood, the transport being perhaps facilitated by intermediate islands now submerged. That the isolation of these islands is anterior to the glacial period follows from Hooker's observation, that whereas in all continental mountains boreal forms are found, the fragments of an expelled flora, the main body of which has returned northwards, the mountain flora of these islands is simply that of the low grounds. The antiquity of these islands is further shown by the distinctness of the pliocene fossil shells in the adjacent islands of Madeira and Porto Santo, and by their equal distinctness at the present time. The Galapagos Islands have a fauna of land birds, all belonging to S. American types, yet four-fifths are peculiar, whereas an equal proportion of the aquatic birds are of S. American species. In the Atlantic islands the birds are tolerably equally diffused, probably by aid of winds; but the calms of the Galapagos area explain the restriction of some of the birds to separate islands. These facts are explicable on the assumption that the isolation of these islands is of great antiquity, and that the presence of forms belonging to adjacent islands is in proportion to their means of transit, as in the case of birds and bats, or to the likelihood of their being drifted by help of ice, floating wood, or in the mud adhering to the feet of birds; that these importations are not of frequent occurrence, and that the forms thus isolated have varied so as to lose their identity with the parent stocks, as has happened in the case of Australia. The student will find in Mr. Wallace's book on the *Malay Archipelago*, an admirable statement of the method of investigating the differences of life in adjacent areas, and of the geographical evidence which may be elicited from them.

419. Hypothesis of Lost Continents.—As our knowledge of the various means by which plants and animals may be transported increases, it is less necessary to assume the former evidence of hypothetical land connections. A miocene Atlantis, across which American plants migrated to Europe, is especially unnecessary, since the existence of miocene plants in the far north suggests their passage in that region, and likewise explains the common characters of the vegetation of the then northern continents; and in the second place the miocene corals, common to Europe and the West Indies, required open sea in the Atlantic, or at least a more or less scattered archipelago, a supposition quite in accordance with the facts above stated. The absence from Madagascar of widely distributed African mammals has suggested the former existence of a continent in the Indian Ocean; but the presence of lemurs on the African shore, seems to indicate a former land connection with Africa at a period so remote that time has sufficed for the variation of the isolated species, so that nearly all are now peculiar. Moreover, the presence of a lemur in Europe in miocene times renders more likely the existence of dry land where the Mozambique Channel now is. The land connection with the Pacific area is supported by the affinity of the insectivore *centetes* to the American genus *solenodon*, and by the presence in Madagascar of American types of serpents and insects.

420. Marine Provinces.—Continuous as the sea appears, it is mapped out into provinces as distinct, though more extensive, than those of the land. The fishes have free powers of locomotion, but they are as much addicted to particular localities as the birds, while it is less easy to recognise the conditions on which their limitation depends. The species associated in the bathymetrical zones, already mentioned, are as local as the inhabitants of subaërial plains, and after the limit of influence of surface temperatures is passed, the species become more extended in range, just as the mountains, even to the equator, support boreal forms. The littoral species are the most varied, they being most under the influence of seasonal vicissitudes, and diversity of soil and food.

The provinces of terrestrial life have their analogues in the sea.

421. N. Atlantic.—The North Atlantic province includes a large part of the Arctic shores of the Old and New Worlds, and extends far down the American coast on the one side, the European shores on the other: the Mediterranean and Aralo-Caspian lakes belong naturally to it, and its southern limit is the equatorial drift. Over all this area the living and the most recent tertiary species of mollusca agree, and the characters which unite so large a tract under one designation are due to the dispersive power of the glacial cold, whereby boreal forms are now located in the Mediterranean, and the affinities of that sea with the Indian Ocean have been greatly reduced as compared with what they were in pliocene times. The adherence of cod, salmon, and herring, to the coast lines is as marked as that of the molluscs, and confirms the view that the community of species on either side, amounting to nearly one hundred among the molluscs alone, is due to the existence of a former land connection in the far north.

422. Caribbean Province.—This area extends from Concepcion on the west coast of S. America, to the outflow of the Gulf Stream. Its molluscs, by which chiefly the province is determined, merge into each other, the Falkland Isles (Malvinas) proving their antiquity by the possession of 73 per cent. of peculiar species. The fauna of the Mexican Gulf includes a large number of corals, but its molluscs have about 3 per cent. of species common to the western side of Darien, and some of the common species are found also in Western Africa. The transport of these species by the equatorial drift, and their migration westward during the patency of a channel through the Isthmus of Darien, is an event of the same kind, probably, as that by which a few species have been carried by the Gulf Stream to the shores of Britain. But when it is remembered that of 522 Sicilian species, thirty-five are common to the West Indies, and twenty-eight to the west coast of Africa, it is possible that the extension of species from Panama to Africa may have occurred at the same time, and by the same means, that Central Europe and the West Indies shared their coral fauna.

423. Indo-Pacific Province.—This, the largest marine area, is still imperfectly known. Following the coast line, a remarkable continuity of molluscan forms can be traced, and such agreement as the Pacific Islands present with the American continent, ceases at the Peninsula of California. The sea lions range throughout this great area, and even beyond it, manifesting as little agreement in detail with the *regions* marked out by terrestrial life as do the other animals possessed of various powers of locomotion, with the areas whose limits have been marked out by Mr. Wallace. The area is predominantly that of corals, and the specific variety of the mollusca is due to the multiplicity of local conditions arising from the submergence and re-emergence of lands whose prominent peaks have been seized on by the corals (see page 66 for the axes of Pacific lands). In this region, too, are found the remains of the decadent group of cephalopods, which filled the mesozoic strata with ammonites, but is now reduced to the nautilus.

424. Australian Province.—The large number of peculiar genera, and of genera which here attain their maximum, gives as marked a character to Australia as it owes to its terrestrial fauna, more especially as mesozoic types are conspicuous. But the common genera are also of interest, since they are, with unimportant exceptions, found in the southern land masses of America and Africa, as well as on the shores of the Antarctic continent.

425. Western S. America. — The Gulf of California belongs to the great province of which Panama is the centre, and whose southern limit is the margin of the easterly or Antarctic drift. The community of forms on either side of Darien has already been mentioned; it only remains to say that the total difference of the molluscan fauna of the Indo-Pacific from that of this portion of America, renders the region thus limited a very natural one. The Galapagos Islands maintain in their marine fauna the preponderance of peculiar forms seen in their terrestrial population.

426. Pelagic Forms.—The conditions of migration of some families of animals are unknown. Cuttle fishes are found in most regions, but the species, though dwellers in the high seas for the most part, are very conservative of their customary tracks. If it is difficult to follow the movements of an animal like the herring when it approaches the coast, it is impossible to say how the pelagic species travel, and our marine provinces are therefore defined entirely by reference to the coast faunas.

427. Deep Sea Faunas: Continuity of the Cretaceous Epoch.—Only in the Atlantic Basin have soundings as yet given *systematic* information regarding the inhabitants of a depth beyond 200 fathoms, and even there, great as has been the addition to our knowledge, the observations are few and isolated. It appears that the oaze, often referred to, represents the chalk of the cretaceous formation, its large amount of diffused silica not having yet been segregated in the flint nodules of the old rock; that the area occupied by the deep water species is wider than that of the shallow water forms; and that while the propriety of including within one area the regions mentioned in a previous paragraph is confirmed by the presence of miocene and pliocene Sicilian forms, in others a remarkable affinity is shown to the cretaceous forms. The continuance of these forms, belonging to types supposed to be extinct, in association with a deposit so peculiar, one which from theoretical considerations we should expect to find, as it is known to be a deep water accumulation, has given grounds for the generalisation that the chalk is continued to the present time. Whatever exception may be taken to the phrases in which this idea is embodied, the fact is, that the cretaceous deposits persist with very much of their characteristic fauna, and that thus two provinces co-exist, which, judged by the palæontological standard, would be regarded as belonging to distinct periods of time. It further appears, as Dr. Wyville Thomson points out, that "the gasteropods range from the shore to a depth of 100 to 200 fathoms, the lamellibranch molluscs become scarce at a slightly greater depth, while some orders of brachiopods, crustacea, echinoderms, sponges, and foraminifera descend in scarcely diminished numbers to 10,000 feet. In fact, *the bathymetrical range of various groups in modern seas corresponds remarkably with their vertical range in ancient strata.*" The sentence which we have italicised contains a generalisation which accords with that of Agassiz as to the order of the genera of corals in a reef, the representatives of the groups whose maximum was in the remote past being near the bottom, the modern species towards the surface of the reef.

428. Extinction and Replacement of Species.—The disappearance of species is very slow, and the final extinction can very rarely be determined. The lists of fossils given in works on geology show that a species may not occur in every successive series of strata in one region; but its absence in any particular layer may be due to its migration elsewhither, or to our imperfect knowledge of the layer, as well as to its extinction; and one of the former is clearly the explanation when it occurs in the layer above. The colonies of M. Barrande show how extensive migrations may be, and how long an interval may separate the earlier and later occupancy of a region by the same species. As there is no reason to believe in the sudden and entire destruction of a species, which, so far as evidence goes, could only take place with a decaying species, whose numbers and area were therefore already greatly reduced, the sudden sharp cessation of, say, the mesozoic types in Britain at the close of the chalk, is due to migration and to the nonpreservation of the highest strata of the chalk series. For the same reason the replacement of species is a process not traceable, even if it were effected only by migration; still less can the steps be followed when modification is instrumental in the changed aspect.

429. Persistent Types; Progressive Development.—It is impossible to enumerate the influences by which plants and animals are altered, destroyed, or displaced; but to the external agents must be added one whose power we cannot estimate, namely, inherent tendency to decay. If there is in species a natural period of existence, as there is in individuals a limit to functional activity, it is not probable that the full period of duration is often attained, since species are subjected to ever-varying external influences. It is not necessary to argue against theories of progressive development, as that term was understood some years ago. It is now well known that the earliest fossils with which we are acquainted belong to types as well developed as those of the present day; and that while new orders have made their appearance, they have done so, for the most part, at remote dates. Vertebrates, fishes, are found in the silurian series, molluscs of various groups, the lamellibranchs, gasteropods, and cephalopods, are all present in the same strata: brachyurous and macrurous crustaceans (of which the crab and lobster are the familiar living examples) appear in the carboniferous rocks, along with sharks and highly-organised labyrinthodont amphibians. In the triassic strata all the orders of reptiles, except serpents, are represented. Birds are found early in the jurassic series;

and the lower tertiaries contain nearly, if not all, the orders of mammalia. But these higher types not only appear very early, they also persist for long periods alongside of the lower types. Thus trilobites are still found in the carboniferous rocks with the decapod crustaceans mentioned; the labyrinthodonts still flourished in the triassic times, along with the reptiles; the marsupials, which still exist, commenced their career early in the mesozoic series. Among the invertebrates similar cases are found. The classes, crustaceans, insects, myriapods, and arachnids, are all found in the carboniferous, and of the orders of insects several have appeared in strata lower than the cretaceous, deposits; and in the shores of the chalk sea air-breathing gasteropods of the genera *Physa* and *Paludina* lived in lakes and lagoons, over which dragonflies hovered, while beetles (*Buprestes*) crept through the decaying plants on the margin. The orders, then the types of structure, are of great antiquity, and those which have disappeared have given place to more specialised forms, in which, that is to say, the adaptation to particular conditions is more complete. But genera are also very persistent, many dating from the early silurians, as *lingula*, *rhynchonella;* and others appear at successive periods, lasting, with little change, to the present time. On the theory of the origin of species by descent with modification, the early appearance of so many highly organised forms is explicable by their origin in pre-existent common ancestors, not by their evolution each out of the other. But it is clear that, in the first place, this requires the earliest plants and animals to have been in existence long before the cambrian, perhaps even before the laurentian; and thus we should be without fossil evidence of a population as important, and, for aught we know, numerically as great, as that of the present time. In the second place, there is still greater proof, in the fact stated, of the existence of zoological provinces distinct from each other even at the earliest times. The provinces, as they existed in the later palæozoic and earlier mesozoic periods, have been sketched out, but the consideration of them, of their differences from those already given, belongs more properly to descriptive geology, in connection with which the relations of this triassic continent will be discussed.

CHAPTER X.

HISTORY AND DISTRIBUTION OF MAN.

Diffusion of Man—Unity or Plurality of Mankind—Are Races Species? —Bases of Classification—Language—Form of Skull—Hair: Woolly and Straight Haired Races: Melanoi, Xanthomelanoi, Xanthochroi, Melanochroi, Negroes, Negritos—Antiquity of Man—Evidence of Antiquity—Prehistoric Periods—Stone Period —Metallic Age—Primitive Home of Man—Hypothesis of Lost Continents.

430. Diffusion of Man.—The diffusion of man over the surface of the globe, and the permanent footing he has secured in all regions—save those polar and tropical localities in which cold on the one hand, drought on the other, forbid the presence of animals and vegetables in sufficient quantities, or for long enough periods, to supply his wants—are sometimes referred to as if they were characteristics of man alone, and implied an inherent power of adaptation to various external conditions. But his history, and the analogy of other animals, justify the opinion that this power of endurance and of adaptation is an acquisition requiring long time for its full development; and even now there are certain limits beyond which his skill and energy cannot carry him in the struggle with nature. The Bengali and the Esquimaux cannot occupy in permanence each the other's country; and though the native of temperate regions has greater tenacity than he who is subjected to extreme conditions of temperature, there is no instance of the permanence of a race from temperate regions in tropical countries, in which intermarriage with natives and a steady stream of immigrants have not shared in bringing about the result; while the change which the descendants of the British colonists in North America and Australia have undergone, shows that the permanent occupation of a country does not imply the maintenance of the original character of the people. Mr. Bates has given strong reasons for believing in the comparatively recent occupation of South America by the tribes which we speak of as native; but the facility with which the Negro has become acclimatised in the same area shows that the power of adaptation does not depend on the relative elevation of a race, the Negro and the South American being nearly on the same level. The difficulty of determining the conditions of the problem is increased by the fact that, while certain anatomical differences can be recognised between the races in different regions, none of them account for the physiological dissimilarities which we know to exist.

431. Unity or Plurality of Mankind.—Two opposite opinions are held regarding the origin of man. According to the one, the varieties which now people the world are the descendants of a single pair; the other assigns the varieties to a plurality of ancestors. The latter view may be set aside as not resting on sufficient evidence. The monogenists, as the advocates of the former view are called, believe that the ancestors of mankind were specially created in one locality, and were most probably a single pair, or that they were developed by evolution out of lower forms, and that they were a pair or several, but in either case appeared in one locality. It is erroneous and unjust to assume, as is too frequently done, that this last view excludes the influence of that higher power which is more conspicuously appealed to by the hypothesis of special creation. The hypothesis of evolution has been adopted in the case of plants, and animals other than man; and it is here again adopted because it affords adequate explanation of a larger number of phenomena which are related to each other as antecedent and consequent than does any other hypothesis.

432. Are Races Species? Bases of Classification.—This is not the place to enter into the discussion of the question, Are races of man varieties or species? The grounds on which they have been regarded as sub-species, that is, as presenting variations more constant than is usual with varieties, but which cannot be certainly regarded as of specific value, are chiefly: (1) that the variations are not universal in each race, intermediate forms being found which might be referred to other races; (2) that there is no certainty that any races are mutually infertile; (3) intellectually, all the races are so equally endowed as to establish the probability of their identity.

The characters on which the varieties are established are, the form of the skull, the complexion, and the quality of the hair, points which, though not themselves of absolute value, nevertheless characterise very well the great groups.

433. Language.—There is no reason to believe that language differed as to its origin from man's other characteristics, or that its development was other than gradual. But this analogy with physical phenomena leads us to anticipate that philology should be an uncertain guide to the original relationships of races.

At the present time, apart from the facility with which some tribes, who have no written language, acquire the language of their neighbours or invaders; apart from the evidence we possess that a national speech may be washed over by others, so that language alone would fail to reveal the original relations; setting aside also the fact, important though it is, that the ultimately dominant speech is not always that of the dominant race; that, in fact, whereas the spread of physical characters in the animal and vegetable world is in the ratio of the numbers of individuals who present them, speech is extended sometimes by the weaker in numbers and tenacity—setting all these considerations aside, we find that among uncivilized tribes superstition plays an important part in modifying the language, the taboo of the chiefs, and that consequent on death or misfortune, leading to the abolition of words which are replaced by arbitrary symbols, at least this is the case in Africa. The roots, therefore, of the earlier speech are not certainly transmitted; and their comparative fixity at later periods is chiefly helpful in tracing migrations. In other words, the physical differences between the Aryan and Semitic races are less than the linguistic, the distinction having been perhaps exaggerated by some such influence as that just mentioned. It will appear, from the subsequent paragraphs, that the general statement regarding the westerly tendency of nations is true only for the latest dispersion of the Xanthochroic races: that a portion of that stock migrated towards the south-east, and that the diffusion of that great section of mankind has had its movement largely determined by circumstances. Thus the westward movement from Asia was a *necessity*, since the east had been already occupied by the descendants of the people who first tenanted that southern continent, of which fragments only survive. Alternate eastward and westward movements are historically known among the Mongols. The Malay has spread to south-east and south-west. And at the present day the European nations are throwing off their surplus population in all directions, but chiefly where the indigenous people are not strong enough to hold their own, where the climate is not bad enough to kill the immigrant within a few years, and the soil or native productions are not poor enough to forbid the hope of great gain with moderate labour.

But if the material of language does not give positive evidence as to the ancestry of nations, its structure has been found to indicate their grade of development. Languages were grouped by Humboldt as isolating, agglutinating, and inflectional; the simple apposition of the roots, as in the old Chinese, being the lowest of a series which culminates in the highly complicated grammar of European tongues, in which prefixes and suffixes are now merely symbols of particular kinds of relation, are merely the faint shadows of words which had primarily an independent existence. These words have undergone two kinds of change, a logical and a physical. The latter, called by Müller phonetic decay, is a convenient index of the former, or at least of the extent to which it has gone. It must be remembered that what he denominates decay, ought on the hypothesis of evolution to be called progressive adaptation; for that hypothesis includes language among those phenomena which are of slow development and of changing type, while Müller starts with phonetic types or roots which he thinks exist by nature, change of which is a departure from the standard, and in his view decay. But without accepting the interpretation, Müller's summary of the facts is a useful one, and is here subjoined in tabular form, Humboldt's classification being placed alongside of it.

	Müller.			*Humboldt.*
	Aryan *suffixing.*	Semitic *prefixing.*	Semitic *affixing.*	
1.	RR	Chinese		= Isolating.
2.	R+g	g+R	g+R+g	= Agglutinative.
3.	rg	gr	grg	= Inflectional.

[4. R+g+r (?) Bask and American, polysynthetic.=Incapsulating].

In this table, R = symbol of a root which has suffered no phonetic change; r = symbol of a root which has lost its primary significance, but without having undergone phonetic change; while g represents roots which have undergone both processes, and in respect of their loss of meaning relative to the objects which they primarly indicated, may be called dead or empty, though as the exponents of new relations (for they multiply as the life of nations becomes complex), they have acquired new vitality. The student will find the ample discussion of these topics, and of the origin of language, in Max Müller's writings, especially the *Stratification of Languages;* in Farrar's *Essays;* and in the works of Sir John Lubbock and Mr. E. B. Tyler, on *Primitive Civilization* and *Primitive Culture of Man.*

434. Form of Skull.—The terms used in the subjoined table, as descriptive of the skull forms, have reference to the proportions of length to breadth; the length being taken as 100; thus an extreme transverse diameter of 7 inches, with a length of 9 inches, would give the proportion, 9:7 or 100:77·7 = index ·77.*

I. BRACHYCEPHALIC.	
Round Skulls.	Cephalic Index ·80 or more.
Brachistocephalic.	Index at or above ·85
Eurycephalic.	,, ,, ·85 to ·80
II. DOLICHOCEPHALIC.	
Long Skulls.	Cephalic Index below ·80
a. Oval Skulls.	
Sub-brachycephalic.	Index ·80—·77
Orthocephalic.	,, ·77—·74
Mecocephalic.	,, ·74—·71
b. Oblong Skulls.	
Mecistocephalic.	Index ·71 and less.

This mensuration does not give information regarding the facial angle, or inclination of the facial profile to a horizontal plane drawn from the anterior end of the cranial axis, which is 67° in the young Orang, 70° in the Negro, 85° in the European. Neither does it tell of that relation of the incisors which furnished Retzius with the subordinate characters, orthognathous when the canines are vertical, prognathous when they are inclined. These features accompany any proportion of skull, the dolichocephalic Negro, and the brachycephalic Mongol being prognathous, the dolichocephalic Aryans and the brachycephalic Peruvian, orthognathous.

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* *Prehistoric Remains in Caithness.* Laing and Huxley, p. 85.

435. Hair: the Distinction between the Woolly and Straight Haired Races.—Ulotrichous and Leiotrichous, trivial as the distintion may appear to be, correspond to important differences in character, capacity, and geographical distribution. The following table shows the results of the application of the tests, skull form, and hair character.

		Dolichocephalic.	*Brachycephalic.*
ULOTRICHI.	Wooly haired,	Negroes; Bushmen.	
	Crisp haired,	Negritos;	Andaman Islanders.
LEIOTRICHI.	Melanoi, . .	Australians; Dravidians; Ancient Egyptians.	?
	Xanthomelanoi,	Esquimaux; Tunguses; Americans; Polynesians. . .	Mongolians.
	Xanthochroi,	Belgæ; Modern S. Germans and Swiss; Finns; Slavonians.	Scandinavians.
	Melanochroi,	Silures; Iberians; Dark Aryans.	

436. Melanous Races.—The aboriginal Australians are among the lowest, both physically and mentally. Their prognathous skulls are small and long, the prominent superciliary ridges are solid. Their skin is dark chocolate-coloured; the hair black and wavy; the eyes dark. The nose, though broad, is not flattened, and the lips, though thick, are mobile, as compared with those of the Negro. When first known to Europeans, they were ignorant of agriculture, the manufacture of pottery was unknown to them. Even in weapons they were deficient, not possessing the bow and arrow, those commonest weapons of the savage; but, on the other hand, they are almost the sole possessors of the boomerang, while the Esquimaux share with them the *use of the* throwing stick. With an extensive sea-bord, they had very inferior canoes, and only the western Australians had fishing hooks and nets. Their unity of descent is not incompatible with the great dialectic differences which Friederich Müller points out as separating the tribes. These are rather to be expected among people long resident in an isolated continent, and grouped in tribes, which a not over-plentiful sustenance kept in unceasing hostility.

The primitive inhabitants of southern India, the Dravidians, belong to this physical type. Largely displaced by the Aryan invaders from the north-west, they still number over 32,000,000, a fifth part of the population of India. Five linguistic divisions are recognised: Tamil, which is spoken over the Carnatic and north Ceylon; Telcgu, misnamed Gentoo, on the east coast; Kannadi, at Mysore; Malayalma, on the Malabar coast; and the decadent Talu of Mangalor.

The people who occupied south and west Europe in prehistoric times presented the same physical characters, so far as may be inferred from their remains, and were either pure representatives of the Melanous group, or were the earliest members of that group, the Melanochroi, to which the Xanthochroi and Melanoi contributed. In either case, there was, on physical evidence, a continuous band of uniform characters from Australia to western Europe, and it is noteworthy that this band manifests likewise a remarkable uniformity of megalithic structures from the Penrose Islands to Scandinavia.

437. Xanthomelanous Races.—The north-east of Europe, Asia north of the Caucasus and Himalayas, large part of the Pacific Islands, and the whole of America, are occupied by races which have a yellowish or reddish-brown tint of skin, dark eyes, and black hair, usually long and straight. The Asiatic types, inhabitants of the fertile plain of China in the east, and of the deserts to the west, the Mongol, the Thibetan, and the Chinese, agree in the brachycephalic character of the skull, in the squareness of their faces, the breadth of the cheek-bones, the usually oblique position of the eyes, and their long, straight black hair. Some of these characters become less conspicuous as we go southwards along the east shores of Asia, and in the Malayan Peninsula we find a race agreeing in complexion, in colour of hair, and in features, with the Mongol, and connecting that group with the inhabitants of the Pacific Islands as far south as New Zealand. The Esquimaux or Innuit, in the north of America, and with him goes the Greenlander, represents the dolichocephalic type, to which the Samoiedes and Tunguses of northern Asia may be referred. They are of small stature, broad faced, dark olive brown, with black hair, and the skulls are low as well as long. These latter considerably resemble the Mongols, even to the obliquity of the eyes, while their language is structurally related to that of the North Americans.

The other inhabitants of the New World, setting aside the European, African, and Chinese colonist, agree generally in having a complexion which is some shade of brown, or even olive; in having dark eyes and straight black hair. The skull is broad, high, and long, the length being greater in the northern and eastern tribes than in those to the south. The face is broad, and the beard is slight. It is impossible to recognise any important physical distinction between the native peoples of America.

The Fuegians are at present the most wretched of people. Their chief food is molluscs, fish, which they eat raw, bones, and scales, and blubber, when it can be procured, whether fresh or putrid. With very scanty clothing at best, they and their sucklings are often naked during snowfall. They have no pottery, and scarcely any weapons. There is reason to suspect that they are brachycephalic, and that the difference which exists between them and the other South American tribes, may be due to divergence from a common stock.

438. Xanthochroic Races.—The combination of abundant fair hair, blue eyes, and a pale skin, with a short skull, is found in the Scandinavians, with a long skull in the Belgians, South Germans, Swiss, Finns, and Slavonians. These peoples at an early period occupied the centre of Asia, between the Siberian low grounds and the Himalayas, from the confines of China westwards by successive migrations till they reached the extreme confines of Europe, the shores of the Atlantic, while southwards they encroached at intervals on the civilization of Greece and the power of Rome.

At present they occupy Europe north of the Alps, mingling in Russia with the Mongol, and in Britain with Melanochroi.

439. Melanochroic Races.—From the plains of India to Britain, there may be traced along the track of the races referred to under Art. 436, a series of peoples agreeing in that they possess a pale complexion, with dark hair and eyes, and for the most part dolichocephalic skulls. These peoples occupy Persia, western Asia, and both shores of the Mediterranean, being mingled in France and Britain with the preceding stock, which invaded and partly replaced them. In former times they occupied Spain, south France, and probably large part of western Europe, including Britain. It is obvious that this mode of grouping races breaks up the Aryan peoples into two distinct groups, the Xanthochroic and Melanochroic, and while one division of the Celts belongs to the former, the latter includes the dark Celts and the Semitic tribes. Mr. Huxley is inclined to regard the Melanochroi as an area of population which owes its character to the spread of the Xanthochroi over earlier Australoid races.

440. Negroes, Negritos.—From Tasmania by New Caledonia, Papua, and Madagascar, a broken line of Ulotrichous peoples may be traced, and on the other side of the Mozambique Channel the same type extends over Africa south of the Sahara. But again, in Africa, as in Australia, the antiquity of the continent, and the isolation of its people, have given rise to great diversity in speech, the dialectic varieties being numerous and important. The woolly hair of the Negro is evenly distributed over the head, and, taken in conjunction with his black skin and prognathism, which gives his thick immobile lips remarkable prominence, gives him an aspect which is more characteristic than that of any other stock, the oblique-eyed Mongol alone excepted. The Negro is a cultivator of the soil; within the last few hundred years he has acquired the art of dealing with metal: his weapons are the spear, bow and arrow, and are always carefully made, often elegantly finished and ornamented.

The yellow-skinned Bushman has his hair disposed in locks, not uniformly distributed. Inferior in size and strength to the Negro, he also occupies a lower place as regards his civilization.

The Negritos of Tasmania were dark, prognathous, and dolichocephalic, while their frizzly hair separated them from the Australian. Their civilization was even lower than that of the Australian, since they had no canoes, very imperfect fishing apparatus, and not even the throwing stick as a weapon. The Papuan, as described by Wallace, is of a sooty brown or black, nearly but not so jet black as the Negro. The harsh, dry, tufted hair, at first in short curls, forms in the adult a thick mass projecting from the head. The nose is prominent, broad, but not flattened. Apart from the volatile restless energy of the Papuan, characters in which he contrasts with the Malay, the distinctness of the races is evidenced by the fact that members of the Negrito stock now form the population of the interior of many of the islands, and stand to the Malay of the coast in the same relation as the Dravidian to the Aryan, save that the antagonism between the former two stocks is greater, and has resulted in the more depressed state of the earlier people, driven into the fastnesses of the island for safety from their conquerors.

441. Antiquity of Man.—What was the date of man's first appearance, it is impossible to say. In Europe, human remains are found under circumstances which prove him to have been the contemporary of the reindeer, elk, rhinoceros, mammoth (*Elephas primigenius*), and other animals which are now either extinct, or are the characteristic inhabitants of other regions. Thus the west of Europe was already occupied by man long before the Xanthochroic races spread from central Asia. At Hoxne, in Suffolk, flint weapons have been found in a deposit which lies on a hill slope, and which is evidently the remainder of a formation largely denuded during the excavation of the adjacent valley, thus indicating a remarkable change in the physical features of south England since man first occupied it. At present, the earliest indications of man are preserved in the deposits formed during the amelioration of climate after the glacial period. Of miocene man there is no certain evidence, neither can it be held as demonstrated that in America he coexisted with the mastodon. But, bearing in mind what has been said in previous chapters, the student will see that if man lived in central Europe, in the valley of the Somme, when ice covered the river for a large part of the year, there is no reason to doubt, from the analogy of other animals, he must have lived elsewhere at earlier periods. What that locality may have been, we shall immediately enquire.

442. Evidence of Antiquity.—The evidence requisite to prove man's co-existence with extinct animals is:—1. The association of the remains of both in undisturbed deposits, under circumstances which leave no doubt that both had been laid down simultaneously. 2. The absence of rolling, or those signs of friction which would leave no doubt that bodies so soft as bones had been transported for some distance, and might therefore have come from more ancient accumulations. 3. In the case of articles of alleged human manufacture, the appearances must be such that no accidental fractures or other markings could be supposed to coincide.

443. Prehistoric Periods.—Successive epochs of man's history are recognised by the character of the weapons he employed. Three principal epochs are: the Stone Period, the Bronze Period, and the Iron Period, the material used corresponding to the progress he had made in civilization. But these periods, like those of the geological tables, are only true for each country, or each race; they do not mark the same chronological stages for all. Thus the Esquimaux is at the present day in the stone period, while the Hottentot has reached the iron, and these unequal grades are found close to a higher civilization of European origin. Nor is the material necessarily a guide to the degree of civilization, since weapons of the stone age type have been found in America fashioned out of copper, which was easily wrought, but was not used as a metal.

444. Stone Period.—Stone weapons of a rude kind are found associated with the extinct animals above mentioned; while more elegant and beautifully polished weapons of flint and other kinds of stone were carefully prepared at a later date. The periods at which these weapons were in common use are distinguished: the earlier as the palæolithic, or archæolithic, or drift period, the later as the neolithic or polished stone period. The localities in which palæolithic remains are found are limited, and the men who used these primitive tools must have led a life similar to that of the Esquimaux. The river gravels, or drift, or quaternary deposits, the early bone caves, the kjökkenmöddings or shell mounds of Denmark, and the lowest portions of the peat-mosses have yielded the chief remains of this early age. These primitive races were, unlike the Esquimaux, without domesticated animals; yet in some localities, as in Perigord, the designs roughly carved on their instruments show some artistic sense. The palæolithic men seem to have been confined largely to the river valleys, and to the vicinity of the sea, from which food could be more easily obtained, in which it was also more abundant than on the land.

The neolithic age was that in which the tumuli or ancient burial mounds were formed, the Pfahlbauten or lake dwellings of Switzerland were erected, the shell mounds were in part collected, and in which the later cavemen lived. The celts (Lat. *celtis*, a chisel) are most frequently of flint, but other kinds of stone were used, kinds which are not known to exist in some of the countries where the wrought specimens are found. Thus jade in Europe, mica in the Mississippi valley, represent probably barter, and suggest that the tribes, which thus obtained more valuable materials than those at hand, had already attained some mercantile sagacity. The monuments already referred to, as also showing, like the stone instruments, uniformity over a large part of the earth's surface, are the menhirs or standing stones, cromlechs or stone circles, dolmens or stone chambers, and tumuli or barrows of various kinds. These last belong to two distinct types, long and round, and the skulls differ according to the form of the barrow, thus 82 per cent. of long barrow skulls had a cephalic index of ·63 to ·73, while 63 per cent. of those from the round barrows were brachistocephalic. The lakemen of Switzerland belonged to two periods, those of the neolithic having left most abundant remains in eastern Switzerland, the west and central districts containing the habitations belonging to the bronze period, while those of the iron period are represented only on the lakes of Bienne and Neufchatel. Crannoges, as the pile dwellings of Irish and Scotch mosses are called, are found under circumstances which suggest that this mode of securing cattle may have been adopted in later troublous times, but the majority are prehistoric constructions. The existing equivalents are the platform dwellings on the Orinoco, and in New Guinea. It is not possible to determine the races of the neolithic period in Europe; but as we approach the later part of that epoch, it is noteworthy that the size of the weapon handles increases, indicating a corresponding difference in the manufacturers. The shell mounds of Denmark and west Scotland commence in the earlier part of the neolithic period, and extend down to the bronze, while the Tasmanian and Fuegian have within historic times prepared exactly similar piles.

445. Metallic Age.—The gradual amelioration in the condition of the early Europeans, shown by the discovery and increasing dexterity in the use of metals, by the introduction of domesticated animals, and by the greater attention to agriculture, presents a history far too complicated to be more than alluded to here. The range and importance of that history may be inferred from the change of meaning whereby Max Müller shows Aryan roots indicating copper were transferred to iron, and the word which originally stood for fir became *quercus* (oak) while the Greek word φηγος (oak) is represented in Latin by *fagus* (beech); these terms, taken in the order mentioned, corresponding to the order in which the trees succeed each other from below upwards in the Danish peat mosses. Hesiod tells of a period when copper only, not iron, was used, and alludes to a time when weapons did not exist; that is, when metals were unknown. The passage, therefore, from the stone period to the epoch of Greek civilization may have been witnessed by those whose traditions, slowly accumulated, constituted the mythology of early Greece.

446. Primitive Home of Man.—It is clear, then, that man had occupied Europe long, we know not how long, before that period the tradition of which represents the human family as diverging from central Asia. That dispersion was, in fact, the latest event in the history of the race. If our interpretation of events in the palæolithic age is correct, we have evidence of a mode of life not higher than that of the Esquimaux, while every succeeding epoch shows some improvement, some sign of progress. To the question, Did a higher civilization exist at any other part of the earth's surface? it is impossible to reply positively. Following up the line of argument adopted in the previous chapter, the dispersion of tribes from a common centre must coincide with changes both in the travellers and those who remain; and change means progress in the case of man. If, therefore, we find that man in western Europe had not at first risen beyond the conditions of the Esquimaux, it is fair to ask, how low in condition was he in his primitive home? or had he retrograded? The student must, in all such inquiries, bear in mind that retrogression is an uncertain phrase; that the Englishman who spends a winter in the Arctic region retrogrades, inasmuch as his habits are no longer those of his home, but suitable to his surroundings; thus he adopts the custom of eating his food raw, that being apparently most conducive to health. It is open to doubt whether man had not reached Europe before the glacial epoch, and whether the river-gravel folk were not, like the reindeer, driven back from their more northern homes, carrying with them the customs and habits suitable to a rigorous climate. On their retreat northward (for their extinction at that period is an unnecessary assumption), they were seemingly overlapped by the advancing wave of brachycephalic men of the bronze age, and thus the progress of western Europe was made up of that which might result from intelligent efforts to deal with surrounding difficulties, and of that which was borrowed from the invaders. For it must be remembered that man passed through regions of unlike conditions, and his experiences thus varying, his inventions and discoveries would likewise vary. The flint arrow-head was tied on the shaft as the shark's tooth, from which it was copied, was tied on, and the spread of this pattern over inland America is, like the exchange of copper and shells between Lake Superior and the coast, another evidence of the early intercommunication of these primitive folk. But when the comparative facilities for migration offered by Europe and America did not exist, there man was arrested, so to speak, in his intellectual development. His needs were, in the tropical islands, easily supplied; and, in the absence of competition from without, excessive population would be checked, as at the present day in the Pacific and Fuegia, by killing the children and the aged, while the dominant family or families are protected from starvation by the taboo which they lay on the cocoa-nut tree, which thereafter it is a capital offence to touch. Other things being equal, the occupants of an isolated country might be expected to have more and more varied appliances, if they had travelled to it, than if they were isolated after long residence there. The Australian and the Tasmanian are feebly endowed with the appliances for physical comfort: the more migratory Negrito, in addition to the necessity imposed on him by his changes of place, was brought in contact with other tribes, and profited by the contact; hence civilization is greater among that stock nearer the equator than it is farther south. If the student follows up this suggestion, and compares the condition of different peoples, he will find reason to believe that while in all cases a tendency to improve has been shown, and while in very few cases has this tendency failed to produce fruit, the amount of improvement depends chiefly on the necessities imposed by the surroundings of each nation, and thus we have many different stages representing the condition of the people when they first reached localities that did not cultivate their inventive powers.

447. Hypothesis of Lost Continents in Southern Hemisphere.—It is clear that, unless the palæolithic men were created in western Europe, they must have spread from some centre which lay beyond the limits of Europe, and which lay to the south of Asia. The Australian is cut off from his Dravidian kindred by the Negritos, which stretch from New Caledonia round by New Guinea, across the Indian Ocean to Madagascar. The Malay has moved south-eastwards, if we take language as the guide, for the Arabic element disappears in that direction; but did he not first remove northwards? There is abundant physical proof of elevations and subsidences in that great area which lies between Africa and S. America, in the middle of which is Australia, a fragment of a continent homomorphic with the other two. The Tasmanian is a Negrito who cannot have reached his present home by sea, else the tradition of his canoe would have survived, nor was there any system of slavery, before the Europeans arrived, by which the process of transplanting might have been effected. The reasons for asserting the existence of continuous land in the Southern Ocean, at a geologically recent period, were stated in last chapter: from this land, now to a large extent submerged, man probably spread on all sides, not necessarily in every case over continuous land; for navigation undoubtedly had an early share in the dispersal of tribes. The Australoid and the woolly-haired races may be regarded as presenting the two earliest divergences from the common stock, the latter, however, reaching sooner to the limits of their progress than the descendents of the former. The distribution of the woolly-haired peoples is singularly close in its parallelism to that of the marsupials, lemurs, struthious birds, and anthropoid apes, the Sahara sea having apparently cut them off entirely from contact with the primitive dolichocephalic (probably Melanous) races of the Mediterranean shores. The community and diversity of characters between the Mongol and the American are intelligible on this hypothesis. The Malayan type does not appear in southern India, the lines along which the tribes travelled being thus so far parallel, not coincident. The glacial period doubtless suspended the spread and development of man during a considerable period prior to his advent in western Europe. To the period of climatal improvement we ought probably to assign that later dispersion from central Asia which flooded India with pale faces, whose influence is manifested in the mixed stock, the Melanochroic, by which Dravidian tribes are isolated. To this time perhaps belongs the Malayan reflux which has given so great uniformity to the Polynesian area. It is clear that the terms, Aryan or Indo-European, are suggestive of theories on which we cannot decide, for the Xanthochroi may be primarily derived from Asia, east and north of the Himalayas, and Indo-European may thus be only true, in a secondary sense, for their Melanochroic descendants. Be this as it may, the fact is that, while the Xanthochroi are not traced beyond the Himalayas, the Melanochroi—all those peoples with whom religion, science, and art, have attained their earliest and greatest development—all those people to whom grand conceptions, whether in cyclopean masonry, or in gigantic empires, seem natural—extend to the shores of the Indian Ocean.

COMPARATIVE TABLE OF FAHRENHEIT AND CENTIGRADE DEGREES.

Boiling point on the Fahrenheit scale is 212°, or 180°F. above the freezing point (32°), and as boiling point on the Centigrade scale is 100° above 0°, it follows that 180°F. are equal to 100°C., that is, 9°F. are equal to 5°C. The result may be formulated thus:—

$$\frac{\text{Degrees F.} \times 5}{9} = \text{Degrees C.}$$

But as the Fahrenheit scale commences 32°F. below freezing point, the Fahrenheit scale may be reduced to the Centigrade, or Centigrade to Fahrenheit, thus:—

$$(1.) \qquad \frac{5\,(\text{Temperature F.} - 32^\circ)}{9} = \text{Temperature C.}$$

$$\text{Ex.: } \frac{5\,(55^\circ\text{F.} - 32^\circ)}{9} = 12{\cdot}7^\circ\text{C.}$$

$$(2.) \qquad \frac{9\ \text{Temperature C.} + 32^\circ}{5} = \text{Temperature F.}$$

Deg. F.	Deg. F. below Freezing Point.	Deg. C.	Deg. F.	Deg. F. above Freezing Point.	Deg. C.	Deg. F.	Deg. F. above Freezing Point.	Deg. C.
32	0	0·0	32	0	0·0	51	19	10·5
31	1	- 0·5	33	1	0·5	52	20	11·1
30	2	- 1·1	34	2	1·1	53	21	11·6
29	3	- 1·6	35	3	1·6	54	22	12·2
28	4	- 2·2	36	4	2·2	55	23	12·7
27	5	- 2·7	37	5	2·7	56	24	13·3
26	6	- 3·3	38	6	3·3	57	25	13·8
25	7	- 3·8	39	7	3·8	58	26	14·4
24	8	- 4·4	40	8	4·4	59	27	15·0
23	9	- 5·0	41	9	5·0	68	36	20·0
22	10	- 5·5	42	10	5·5	77	45	25·0
21	11	- 6·1	43	11	6·1	86	54	30·0
20	12	- 6·6	44	12	6·6	95	63	35·0
19	13	- 7·2	45	13	7·2	104	72	40·0
18	14	- 7·7	46	14	7·7	113	81	45·0
17	15	- 8·3	47	15	8·3	122	90	50·0
16	16	- 8·8	48	16	8·8	212	180	100·0
15	17	- 9·4	49	17	9·4	...	...	...
14	18	-10·0	50	18	10·0	...	...	...

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